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SURFACE WATER TREATMENT WORKSHOP MANUAL

1976

MINISTRY OF THE ENVIRONMENT
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Ministry of the Environment

The Honourable George A. Kerr, Q.C., Minister

Everett Biggs, Deputy Minister

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SURFACE WATER TREATMENT WORKSHOP

First edition October, 1974
Second edition September, 1975
Third edition August, 1976

Training and Certification Section
Personnel Services Branch
Ministry of the Environment
135 St. Clair Avenue West
Toronto, Ontario M4V 1P5

Other manuals relating to the water and wastewater treatment processes published by the Training and Certification Section, Ministry of the Environment, include:

Basic Gas Chlorination Workshop

Basic Water Treatment Operation

Basic Sewage Treatment Operation

Activated Sludge Process Workshop

Primary Treatment and Digestion Workshop

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INTRODUCTION

The *Surface Water Treatment Workshop* manual was developed primarily by the Water Technology Section, Pollution Control Branch. It has been prepared as a home study and reference manual for plant operators.

The Workshop based on the contents of the manual is of five days duration at the Ministry of the Environment training facilities. The principal objective of the Workshop is to increase the knowledge of experienced water treatment plant operators. The lesson objectives are clearly indicated at the beginning of each topic and tell the operator what he should know or do after having covered that topic. To successfully complete the Workshop, an overall average of 70% is required.

This is a working course in which each person is expected to take an active part in subject discussions. It includes hands-on training in order to provide the trainee with as much practical knowledge as possible of the water treatment process.

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SUBJECT:

SURFACE WATER TREATMENT

TOPIC: 1

Basic Water Chemistry

OBJECTIVES:

The trainee will be able to

1. Identify and distinguish between the chemical terms: atoms, ions, elements, and compounds.

2. Understand the basic characteristics of the elements.

3. Identify the common ions and chemical compounds encountered in water treatment.

4. Outline the basic reactions of:
   a) hydrolysis
   b) chlorine in water and chlorine and ammonia in water
   c) acids - pH adjustment
   d) bases - pH adjustment
   e) alum in water

5. Know the meaning and significance of the terms
   a) pH
   b) alkalinity
   c) hardness

BASIC WATER CHEMISTRY

GENERAL

Society today is becoming increasingly knowledgeable in environmental affairs. Very often, the concern centres around the use and abuse of chemicals. In order to converse with the public on the use of chemicals in his plant, the operator should have a general understanding of chemistry and chemical terminology. In addition, with this understanding the operator will be able to utilize the technical expertise available and will grasp more readily the recent developments in the water treatment field. This section deals with the basic chemical terminology, several chemical compounds and a few chemical reactions pertinent to the water treatment process.

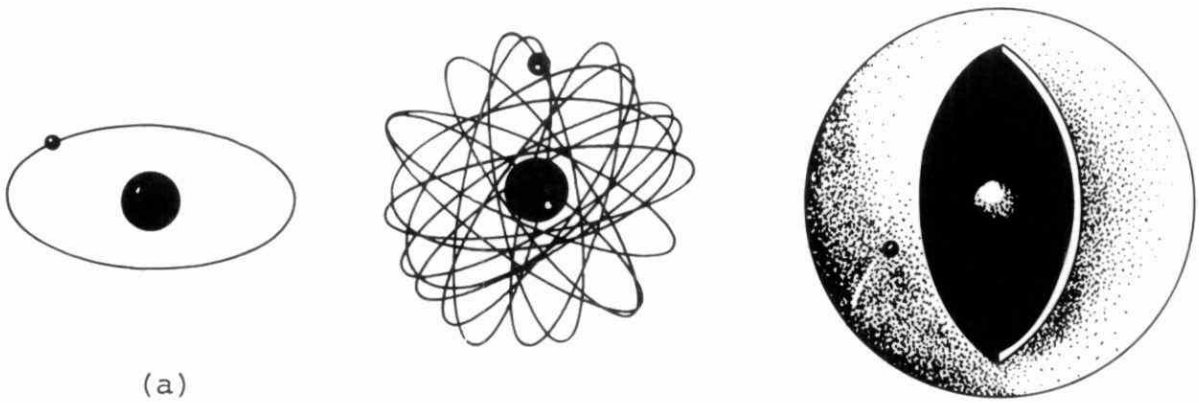
ATOMIC STRUCTURE (What makes up an atom)

All physical substances have two properties in common. First, they are comprised of very small, highly indivisible particles called *atoms*. Secondly, these atoms have an electrical nature that determines their own structure and also their ability to cling (or not to cling) to each other.

Atoms are much too small to be seen even by the best microscope. Even this miniscule size appears to be a volume carved out of "empty space" by still smaller electrical particles called *protons* and *electrons*. By means of an exceptionally violent "dance" of the lighter negatively charged electron(s) about a cluster of centrally positioned positive proton(s), a three-dimensional volume is virtually "buzz-sawed" out of the surrounding space to form the atomic structure.

Figure 1-1 illustrates the atomic structure for the hydrogen atom.

A hydrogen atom consists of a single electron moving around a single proton, like a planet in orbit around the sun, as shown in Figure 1-1(a). The orbit changes its position so rapidly that it seems to weave a solid shell around the nucleus as in Figure 1-1(b). Figure 1-1(c) shows the orbit as a shell but cut away to reveal the proton at the centre.



(a) (b) (c)

Figure 1-1 HYDROGEN ATOM

Completing the picture, additional neutrons (electrically neutral particles) are usually present in the central nucleus serving to hold the mutually repelling positive changes together. Neutrons, like protons, weigh almost 2000 times as much as electrons. Figure 1-2 shows the atomic structure of carbon, with its 6 protons, 6 electrons and 6 neutrons.

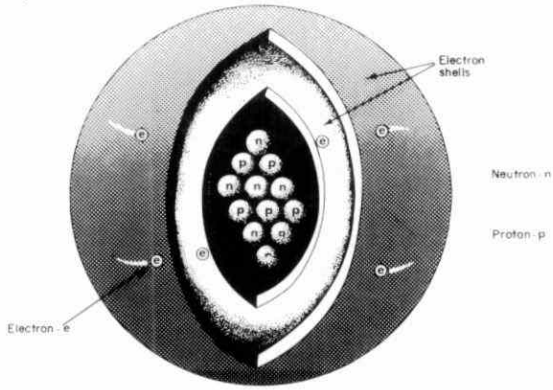


Figure 1-2 CARBON ATOM

THE CHEMICAL ELEMENTS

Although we dwell in a universe consisting of well over 100,000 chemical materials involved in innumerable mixtures, all these materials are merely combinations of just approximately 100 different types of atoms. These basic atoms, belonging to a special group of primary materials called the "chemical elements", can be considered as being derived from just two fundamental electric particles - the proton and the electron. *A simple numerical build-up of equal numbers of oppositely charged particles thus forms the basis for the existence of chemical element atoms with their widely variant physical and chemical characteristics.* The characteristics of these elements are:

1. Each element is virtually indestructable.
2. Each element possesses a different chemical and physical characteristic to another.
3. All atoms of the same element possess identical characteristics.

Example:

one atom of sodium. The atom is called the sodium element.

3 atoms of the sodium element.

Atomic Number

Each of the 100 or so chemical elements can be identified by its own particular number, known as the *atomic number. This number represents the numbers of positive charges, i.e. protons, present in the nucleus of each atom comprising the element.* The series starts at "1" for the gaseous element "hydrogen". Next, when two positive charges lie in each nucleus, atoms of another light gas "helium" are formed. Then an abrupt change in

properties occurs as a light metal, "lithium", is formed as atomic number "3" is reached. The series continues with "berlyllium", "boron", and "carbon" being formed at number 4, 5, and 6 respectively. Further examples of elemental atoms common to water and waste water treatment chemistry may be found in the partial listing Table 1-1 Page 1-5.

Chemical Symbol

Table 1-1 also indicates the "chemical symbol" for each of the given elements. *These "symbols" are but standard abbreviations derived from one or two key letters in each element's name.* The first letter is always capitalized while the second letter, if any, is lower case. Some unexpected letterings are derived from historically used Latin names (in brackets) for some of the elements. An example is the symbol for potassium - K - from the Latin "Kalium".

Atomic Weight

The final column of the Table lists *"Atomic Weights", which represent the relative weights of the various atoms.* This column, for example, shows that an atom of carbon weighs about 12 times the weight of a hydrogen atom; a calcium atom weighs about 40 times as much; and an uranium atom equals the weight of 236 (238.04 divided by 1.008) hydrogen atoms.

Isotopes

Because of the particle by particle build-up of atomic structures by particles with an atomic weight of 1.000, it could be anticipated that all atomic weights should be whole numbers rather than the fraction--including values listed. However, not all the atoms of one element contain the same number of neutrons. This factor results in the creation of elemental *"isotopes" where atoms with the same atomic number (and hence,protons in their nuclei) contain variable numbers of neutrons.* The atomic weights quoted are thus but averages of whole number atomic weights of the isotopes themselves.

Table 1-1 COMMON ELEMENTS IN WATER AND WASTEWATER TREATMENT

Atomic Number	Name of Chemical Element	Chemical Symbol	Atomic Weight
1	Hydrogen (gas)	H	1.008
6	Carbon (non-metal)	C	12.011
7	Nitrogen (gas)	N	14.007
8	Oxygen (gas)	O	16.000
9	Fluorine (gas)	F	18.998
11	Sodium (metal)	Na (Natrium)	22.990
12	Magnesium (metal)	Mg	24.312
13	Aluminum (metal)	Al	26.982
14	Silicon (non-metal)	Si	28.086
15	Phosphorus (non-metal)	P	30.974
16	Sulphur (non metal)	S	32.064
17	Chlorine (gas)	Cl	35.453
19	Potassium (metal)	K (Kalium)	39.102
20	Calcium (metal)	Ca	40.08
24	Chromium (metal)	Cr	51.996
25	Manganese (metal)	Mn	54.938
26	Iron (metal)	Fe (Ferrum)	55.847
29	Copper (metal)	Cu (Cuprum)	63.54
30	Zinc (metal)	Zn	65.37
47	Silver (metal)	Ag (Argentum)	107.870
78	Platinum (metal)	Pt	195.09
79	Gold (metal)	Au (Aurum)	196.967
80	Mercury (liquid metal)	Hg (Hydrargyrum)	200.59
82	Lead (metal)	Pb (Plumbum)	207.19
92	Uranium (metal)	U	238.04

THE CHEMICAL BOND

STRENGTH OF A CHEMICAL BOND

The basic rule of electric charges is that negative and positive charges are forcefully attracted to each other. Atoms, whose very existence is based on the furious motion of charged particles (somewhat mysteriously kept apart), develop residual attractions permitting them to adhere to each other.

The bonding of one atom to another can be very strong or very weak. Iron atoms clinging to one another form a very strong metal. On the other hand, the atoms of the liquid metal mercury show the effects of quite a weaker bonding. Still weaker are the bonding forces unable to hold the atoms of gaseous substances together allowing them to scatter in all directions as in the release of compressed air.

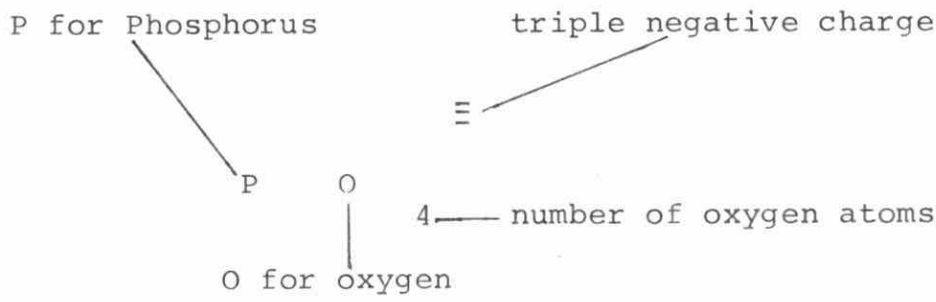
What makes molecules so distinguishable within a substance's great mass of atoms is the fact that the adhesive forces binding the atoms into molecules are so much stronger than the forces holding the molecules in contact. One can, for instance, heat water to cause the molecules to boil away from one another's presence to form steam, the gaseous state of water. But note that the process leaves the molecules themselves intact - that no free hydrogen or oxygen atoms are formed in the process. *If the attracting forces between water molecules were as strong as those within the molecules, water would be a solid substance considerably stronger than steel.*

IONS

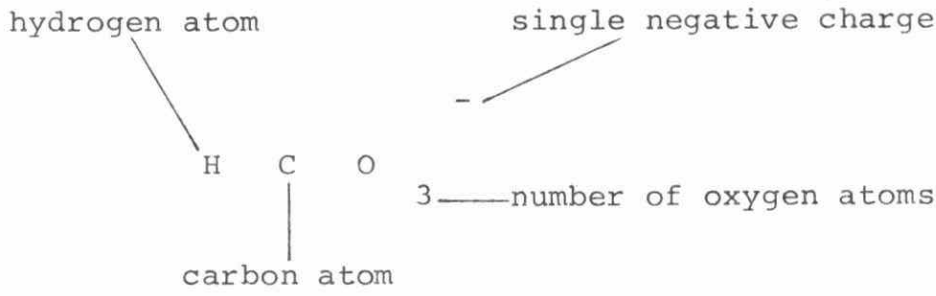
When an acid, base, or salt dissolves in water, some or all of the molecules dissociate (break up) into *ions*. The metallic ions and hydrogen ions are positively charged, while the acid radicals and the hydroxyl ions are negatively charged.

Examples of Ions:

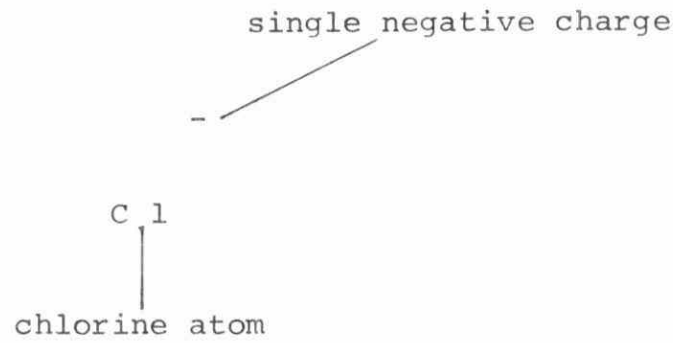
1. Phosphate Ion ($PO_4^{\equiv}$)



2. Bicarbonate Ion (HCO_3^-)



3. Chloride Ion (Cl^-)



The partnership of negative and positive ions with each other, though strong, is generally *"fickle"*. Given the chance ions may change their partners readily. A solvent such as water is relatively effective at dissolving chemical salt crystals because water is capable of providing its own negative and positive ions as competition to the original partners in the dissolving crystal. Moreover, once the ions are separated in solution other ion combinations are easily formed. *This ease of ion interchange to produce new ion combinations (that is, new salts) is of particular importance in water chemistry.*

Electrical Attractions

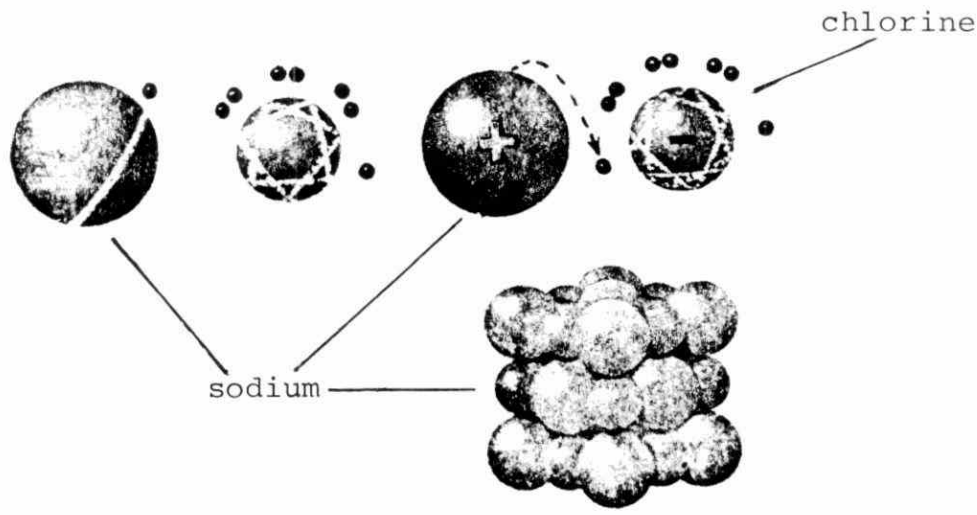
There are three main ways by which atoms develop electrical attractions for adhering to one another, namely:

1. Attraction between ions
2. Sharing of electrons
3. Electrostatic induction

Ion Attraction

Certain atoms or groups of atoms on contacting other atoms or groups of atoms may make a *direct donation of electrons* (the negatively charged particles) *to the latter*. The atoms donating the electrons are left with an excess of positive charges and are therefore labelled "positive ions". The atoms receiving the negative charges become "negative ions".

Oppositely charged ions are strongly induced to draw together because of the very charges that such atoms elected to adopt. Ion-formed materials are commonly known as *"salts"* and are adept at packing tightly together as may be found in ordinary table salt (NaCl - sodium chloride, shown below). Epsom Salts ($MgSO_4$) - magnesium sulphate), alum ($CaCO_3$ - carbonate).



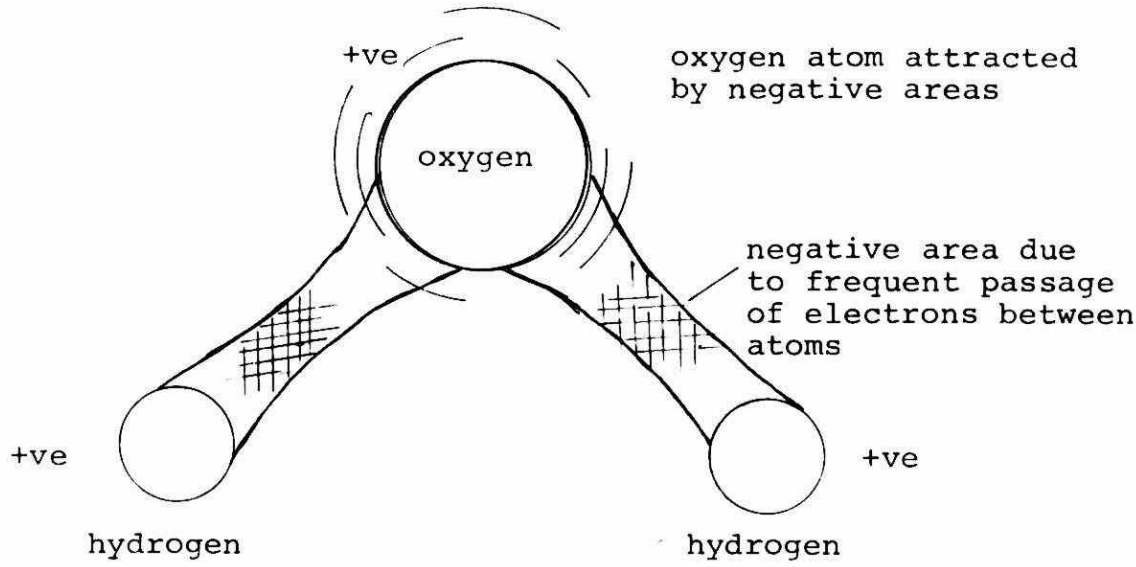
In the above example sodium gives its single outer electron to chlorine which needs one electron to complete its outer shell. An electrovalent substance such as common salt (right)

has no true molecules. It is just a mass of sodium ions embedded in an equal number of chlorine ions as shown.

Electron Sharing

Electron sharing differs from ion formation in that the atoms donating electrons accept them back again quite readily. The result is that the electrons include zipping back and forth between atoms as part of their violent motion about the atoms themselves. As electrons transfer back and forth, "ions" are in a sense being formed, but only on a theoretical or transitory basis. Ion attraction forces contribute to holding the contacted atoms together, but when it comes to demonstrating such ions, the flickering nature of their existence defies detection by the usual method. In this regard, the concept of "ionic" substances is really confined to material exhibiting stable ions not subject to such rapid transitions.

Electron-sharing bonds between atoms may be weak or strong, but not *"fickle"* with regard to partnership as in ionic bonds. Secondary attraction forces in the shared bond assures their constancy. The incessant travel of the negative electrons between atoms develops a "statistical" presence of the electrons in this region at the expense of the electron's full-time presence about the atoms themselves. Thus, the *space between bonded atoms* assumes an average *negative* charge as the *deprived atoms* each assume a slight *positive* charge. The "heavy-weight" atoms consequently drift slowly towards the negative space between them thereby shortening the travel time of the bonding electrons as the original cause of the charge discrepancy. Any attempt to draw such atoms apart, conversely, would increase electron travel periods between atoms and the resultant interatomic forces drawing them back together. In brief, a considerable tug-of-war is required to separate atoms mutually sharing electrons in this manner.

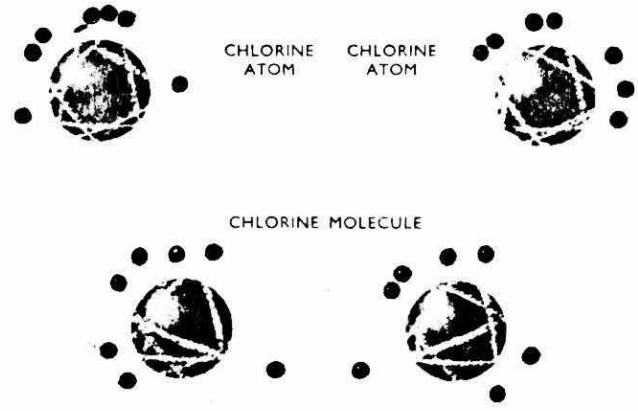


WATER MOLECULE - illustrating the attraction of both the oxygen and the hydrogen atoms to the negative areas and the repulsion by each other when they get near to each other.

Electron sharing is virtually the *universal* bond in chemistry where ion formation is really just an extreme case of very poor sharing of the bonding electrons. The usual textbook name for the electron sharing bond is the *covalent bond* or just *covalency*. Where only one partner provides the shared electrons it can be called "coordinate covalency", and the masses of released commonly shared electrons in electrically conductive metals may be described as an "electron cloud". Virtually all atoms are involved in electron sharing of one form or another.

All the atoms in a molecule are held together by electron sharing as are also the atoms within an ion group. For example, the sulphate ion ($SO_4^{=}$) as found in alum ($Al_2(SO_4)_3$) has four oxygen atoms linked to a central sulphur by coordinate covalency - the sulphur providing all eight shared electrons for the oxygens.

The diagram below illustrates the sharing of two electrons, one from each chlorine atom. Each electron orbits both of the atoms binding them. This sharing of electrons is called *covalency* and the atoms are said to be joined by a covalent bond.



A covalent bond is formed when atoms share a pair *of electrons,* (Basford)

The term "*valence*" in chemistry refers to how many electrons a particular atom contributes (gives, takes, or shares) within a particular chemical combination. A "trivalent" atom such as aluminum normally gives or shares 3 electrons for a valence of 3, whereas a "monovalent" atom such as chlorine normally takes or shares one electron in showing a valence of 1.

Knowing the usual valence of an element and its chemical partners allows one to predict or recall the exact chemical formula of many chemical compounds. Compounds form on the basis that whatever electrons are donated or shared by one species must be accepted or shared by the other partners. Some elements however demonstrate more than one valence under differing conditions so that more memorizing may be required in dealing with the compounds formed of such elements.

Electrostatic Induction

A third adhesive force can be created *without exchange or transfer of electron particles*. Such a force binds *molecules* together and is generally a weaker force. By pushing and pulling on the moving electrons of neighbouring atoms, instantaneous charge distributions of one molecule are reciprocated in adjacent molecules to yield a net attractive force between the molecules.

Such forces are best illustrated by the clinging of charged plastic film to an *uncharged* object such as one's hand. Only because the film's charge can *induce* a local surface charge on the neutral object, is the charged film able to develop an adhering ability.

The clinging of molecules to each other is usually weaker than the forces causing atoms to bind into molecules. As a result the heating of substances (agitation of the molecules) often results in the phenomena of melting and boiling of the heated materials. The molecules of substances such as water, wax, glass etc., may remain intact although heating may cause them to be released from stationary positioning as found in solid substances or from the more mobile associations as found in liquids.

With very large-surfaced molecules such as cellulose in wood or proteins in meat some exceptions can be noted. Heating of these materials results in *charring* before any melting points can be observed. The adhering forces between such giant molecules prove to be greater than the forces that build the molecules themselves. Such molecules break up before they let go of each other as they are agitated by heating.

Ions Important in Water Treatment

For a solid understanding of water treatment and distribution the operator should know the importance of the following:

1. Phosphate Ion $PO_4^{=}$

   Nitrate Ion NO_3^{-}

   because of the nutritional value of these ions to the growth of algae.

2. Sulphate Ion $SO_4^{=}$

   because it is part of the alum molecule and takes part in the alum hydrolosis reaction.

3. Carbonate Ion $CO_3^{=}$

   Bicarbonate Ion HCO_3^{-}

   Hydroxyl Ion OH^{-}

   because they make up the bulk of the alkalinity level in the water.

In addition, *elements* themselves may be found in water possessing a charge. These ions include:

1. Calcium Ion Ca^{++}

   Magnesium Ion Mg^{++}

   which make up the bulk of the hardness of the water.

2. Aluminum Ion Al^{+++}

   which may cause pipeline coatings and after floc formation.

3. Hydrogen Ion H^{+}

   which governs the pH of the water.

4. Fluoride Ion F^{-}

   which helps to prevent tooth decay.

COMPOUNDS IMPORTANT IN WATER TREATMENT

General

A *compound* is a substance which contains two or more *elements combined* together. The combination formed has *uniquely* different characteristics as compared to the original elements. Formulae are used to designate the make up of compounds.

The chemical compounds that the operator should be familiar with include the following:

1. Water
2. Alum and Alum derivatives
3. Iron Salts and derivatives
4. Lime
5. Alkalinity
6. Hardness
7. Chloro-ammonia compounds

Formulae

The bracketing and numbers in formulae associated with many compounds can be explained as illustrated below:

1. Alum $Al_2(SO_4)_3.14\ H_2O$

   This compound is made up of:

   14 water (H_2O) molecules
   3 sulphate ions ($SO_4^{=}$)
   2 aluminum atoms as positive ions (Al^{+++})

   In the sulphate ion, there are 4 oxygen atoms and 1 sulphur atom.

2. Monochloramine NH_2Cl

   This compound is made up of:

   1 nitrogen atom N
   2 hydrogen atoms H
   1 chlorine atom Cl

Compounds and Formulae

Water H_2O, two hydrogen atoms, one oxygen atom

Alum

1. Aluminum sulphate $Al_2(SO_4)_3.14\ H_2O$
2. Aluminum Hydroxide (Alum Floc) $Al(OH)_3$

Iron Salts

1. Ferric Chloride $FeCl_3$
2. Derivatives (Iron Floc) Ferric Hydroxide $Fe(OH)_3$

Lime

1. Dry Lime. Calcium Oxide CaO
2. Slaked Lime. Calcium Hydroxide $Ca(OH)_2$
   (Slaked means it had reacted with water)
3. Limestone. Calcium Carbonate $CaCO_3$

Alkalinity Compounds

As mentioned previously, all carbonates, bicarbonates and hydroxyl ions make up the alkalinity in the water. These ions are usually found in the following compounds:

1. Sodium Bicarbonate $NaHCO_3$
   Calcium Bicarbonate $Ca(HCO_3)_2$ — Bicarbonates
2. Sodium Carbonate Na_2CO_3
   Magnesium Carbonate $MgCO_3$ — Carbonate
3. Sodium Hydroxide NaOH
   Calcium Hydroxide $Ca(OH)_2$
   Magnesium Hydroxide $Mg(OH)_2$ — Hydroxide

These compounds are soluble in water.

Hardness Compounds

The hardness of the water is determined by the level of calcium and magnesium and to a lesser extent the iron, aluminium and manganese in the water.

1. Calcium may be found in the following compounds:

   a) Calcium Bicarbonate $(Ca(HCO_3)_2$

   b) Calcium Hydroxide $Ca(OH)_2$

2. Magnesium is found in:

   a) Magnesium Carbonate $MgCO_3$

   b) Magnesium Bicarbonate $Mg(HCO_3)_2$

   c) Magnesium Hydroxide $Mg(OH)_2$

These compounds are soluble in water and break up into separated ions as they dissolve.

Chlorine Compounds

When chlorine is added to water, it reacts with water to produce HOCl (hypochlorous acid) which for general purposes can be called FREE chlorine residual.

If ammonia (NH_3) is present, the following compounds can result:

Monochloramine	NH_2Cl
Dichloroamine	$NHCl_2$
Trichloroamine	NCl_3

All three of these compounds are measured as the COMBINED residual. The FREE residual plus the COMBINED residual equals the TOTAL residual.

Heat

In chemistry and physics, "heat" is the *total quantity of agitation* added to the atoms and molecules comprising a substance. The higher the temperature, the more violently a substance's particles are flying or vibrating about. Heat causes electrons to whip about their atoms more furiously and this, in effect, expands the material volume taken up by each individual atom. Substances therefore tend to expand on heating as all the component atoms take up more space.

For solid materials, the particle motion caused by heating also causes atoms in contact with each other to vibrate violently in their rigidly fixed position much like the springs in a vigorously shaken box-spring mattress frame. Increasing the temperature increases the motion until at some temperature the rigidity of a solid structure yields to a looser mobile collection of clinging molecules. At this point, melting to form a liquid has occurred.

On further heating the loose association of a liquid can also be broken down, as more intense motion exceeds all the attraction forces between the molecules. From this temperature on, the molecules fly apart in all directions to behave as a gas driven off by the boiling of a liquid.

While *heat* is a quantity of summed agitation, *"temperature"* represents the *intensity* of the agitation - roughly relatable to the *amount of heat in a unit quantity of material*. Just as putting more water in a storage tank is bound to increase the water pressure, so adding heat tends to increase temperature.

CHEMICAL BOND REVIEW

Ion Attraction

Oppositely charged Ions are attracted and held together electrically to form compounds. However they may change partners readily.

Examples:

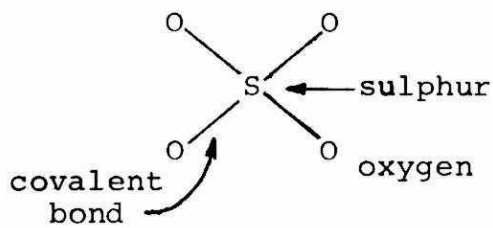
- Salts
- Aluminum Sulphate - Al_2 $(SO_4)_3$
  positive negative
- Calcium Carbonate - Ca CO_3
  positive negative

Electron Sharing

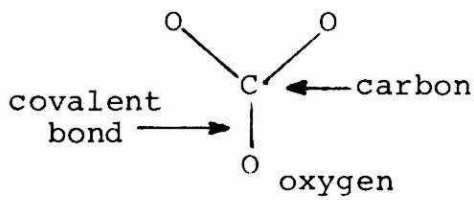
The atoms donate electrons and accept them back between themselves on a continuous basis. The atoms do not change partners readily but the bond may be weak or strong and is called a *covalent* bond.

Examples:

Sulphate Ion SO_4



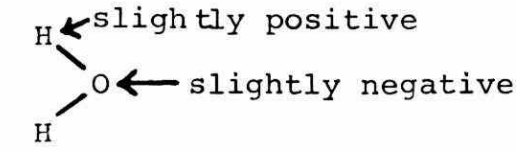
Carbonate Ion CO_3



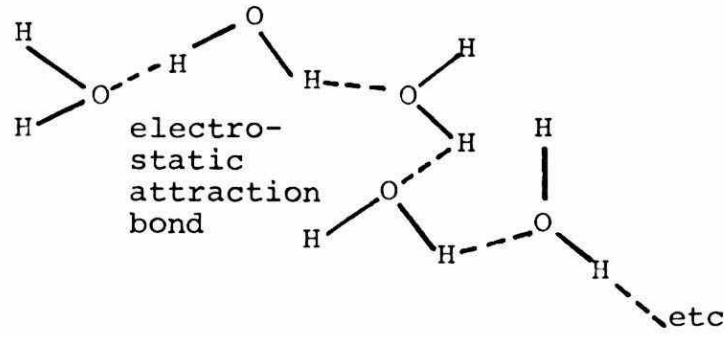
Electrostatic Attraction

Electrical charges within the molecule are altered to yield an attractive force between the molecules.

Example:- Water H_2O



The hydrogen atoms are attracted slightly by the oxygen atoms of other water molecules.



CHEMICAL REACTIONS

Chemical reactions in water occur with the addition of chemicals such as disinfectants or coagulants. The operator should have an understanding of the basic reactions if the public's general inquiries are to be answered.

HYDROLYSIS

The reaction known as hydrolysis is important in chemistry but it is very important to the operation of the water plant. The term *hydrolysis* means *"water-splitting"*. Water (H_2O) is split into hydrogen ions (H) and hydroxyl groups (OH) which then combine in new arrangements.

reversible

$$H_2O \rightleftharpoons H^+ + OH^-$$

water — hydrogen ion — hydroxyl ion

Although water is necessary for hydrolysis, hydrolysis does not take place in all reactions involving water. It is essential that the substance with which the water reacts should be broken up.

CHLORINE

The chlorine reaction in water is mentioned in several locations in this course.
Basically the reaction is as follows:-

$$Cl_2 + H_2O \longrightarrow HOCl + H\,Cl$$

chlorine gas	water	Hypochlorous acid (free residual)	Muriatic Acid

The objective of the water plant operation should be to always produce a water containing a substantial *Free Residual Chlorine* because of its high killing power.

The killing power of chlorine is reduced if organic matter and/or ammonia is present in the water. The reactions between chlorine and ammonia are three-stage depending on the amount of chlorine applied. The resulting reactions may produce:

$$HOCl + N\,H_3 \longrightarrow \begin{cases} N\,H_2Cl & \text{- Monochloramine} \\ N\,HCl_2 & \text{- Dichloramine} \\ N\,Cl_3 & \text{- Nitrogen Trichloride} \end{cases}$$

Free Chlorine — Ammonia

The *combined* chlorine residual is less effective than the free residual in killing bacteria and viruses but it may persist for a longer period of time in the distribution system. Because of this, municipalities favour the addition of ammonia to the treated water to form the combined residual.

It is possible to destroy or burn off ammonia and ammonia-chlorine compounds by the addition of 1 mg/l of chlorine for each 0.1 mg/l of ammonia present in the raw water.

pH GENERAL

The pH of a solution essentially defines the amount of hydrogen ion in solution. The lower the pH, the more hydrogen ion is present. Each unit of pH represents a ten-fold change in hydrogen concentration. For example, a water with a pH of 6.0 has *one hundred times* the hydrogen ion concentration of water of pH 8.0. A completely neutral (neither acidic or basic) water has a pH of 7.0 which represents 10^{-7} gm of hydrogen ions per litre (or 0.0001 mg/l H^+).

Generally, slightly basic waters are less corrosive to metals such as those comprising most distribution systems. In water treatment pH adjustments for corrosion or flocculation control can be useful measures to consider. Acidic materials release hydrogen into solution, whereas basic substances tend to absorb hydrogen ion into less active combinations.

Acids - pH Adjustment

The word acid usually conjures up in the minds of the public the vision of something strong, powerful and dangerous. For the two most important acids used by water plant operators, this is the case; these two acids are sulphuric acid and hydrochloric acid. These are mineral acids because they are manufactured from minerals, not from living things.

Acid consists of the hydrogen part and the acid radical part. When the acid is placed into a watery solution, the two parts split apart and form positively charged hydrogen ions and negative charged acid ions.

$$\underset{\text{sulphuric acid}}{H_2SO_4} \xrightarrow[\text{splits}]{} \underset{\text{hydrogen ion}}{2H^+} + \underset{\text{sulphate ion}}{SO_4^=}$$

$$\underset{\text{hydrochloric acid}}{HCl} \longrightarrow \underset{\text{hydrogen ion}}{H^+} + \underset{\text{chloride ion}}{Cl^-}$$

In the case of strong acids in solution, almost all the acid molecules split giving a high concentration of hydrogen ion. The hydrogen ions released make the water more acidic and lower the pH.

Hydrochloric acid is important in water treatment because of its use in the laboratory as a cleaning agent for glassware. Sometimes it is used for pH adjustment but this is rare because it increases the chloride content of the water. Sulphuric acid is often used for pH adjustment. Concentrated sulphuric acid has a strong tendency to absorb water and gives off heat in the process. Since human cells contain water the effect of sulphuric acid on them is particularly drastic. Care must be taken when handling acids.

Bases - pH Adjustment

There are a number of solutions that can neutralize acids. These substances are called *alkalis or bases.* Examples of common bases found in water plants include sodium hydroxide, calcium hydroxide, and dry lime. Sodium hydroxide (caustic soda) is commonly used for pH adjustment. When the chemical is added to water it released hydroxyl ions,

$$\underset{\text{sodium hydroxide}}{NaOH} \longrightarrow \underset{\text{sodium ion}}{Na^+} + \underset{\text{hydroxyl ion}}{OH^-}$$

which in turn react with the "free" hydrogen ions which are already in solution to form water.

$$\underset{\text{hydroxyl ion}}{OH^-} + \underset{\text{hydrogen ion}}{H^+} \longrightarrow \underset{\text{water}}{H_2O}$$

The *decrease* in the "free" hydrogen ions results in a more *basic or alkali* solution which *increases* the pH.

Similarly, the addition of lime will release hydroxyl ions into solution which will react with and eliminate many "free" hydrogen ions which will in turn increase the pH.

ALUM

The reaction of alum in water is extremely rapid but complicated.

Alum has 17 waters of hydration (17 H_2O), 3 sulphate ions and 2 atoms of aluminum. When placed in water, the 17 waters of hydration go into solution (become part of the water), and the aluminum and sulphate ions break free.

$$\underset{\text{alum}}{Al_2(SO_4)_3 \cdot 17\ H_2O} + \underset{\text{water}}{H_2O} \rightarrow \underset{\text{aluminum}}{Al_2^{+++}} + \underset{\text{sulphate}}{3(SO_4)^{=}} + \text{water}$$

The aluminum ions accumulate hydroxyl ions from the water to form aluminum hydroxide, which is insoluble and which precipitates from solution in a form of floc.

$$\underset{\substack{\text{aluminum}\\\text{ion}}}{Al^{+++}} + \underset{\substack{\text{hydroxyl}\\\text{ion}}}{3OH^{-}} \longrightarrow \underset{\substack{\text{aluminum}\\\text{hydroxide}}}{Al(OH)_3}$$

The former partner of the aluminum ion, the sulphate ion ($SO_4^{=}$), remains in solution replacing the hydroxyl ion that has been taken up by the aluminum.

Since the aluminum ions react with the hydroxyl ions which are formed from the hydrolysis equation,

$$H_2O \rightleftharpoons H^+ + OH^-$$

excess hydrogen ions (H^+) are released. These positively charged ions constitute the pH of the water. A surplus of these ions results in a lower pH. The more alum added, the more hydrogen ions are released to lower the pH, and increase water acidity.

BALANCING EQUATION

Written in a correct mathematical manner, chemical reaction equations represent the precise atomic ratios of chemicals undergoing exchanges of partner. Reaction equations when properly written are balanced such that the number and types of atom entering into a reaction on the left hand side will equal the number and types of atom found in the reaction products indicated on the right hand side. In brief, the material thrown into a chemical reaction must equal the mass of material resultant from the reaction. All that the reaction equation is expressing is merely the change in the atomic partnerships that is being effected.

For example, a reaction between ammonia and chlorine to form dichloramine in shown on Table 1-2 page 1-27; that reaction between sodium sulphate, chlorine and water is shown on Table 1-3, page 1-28.

Table 1-2 Reaction Ammonia and Chlorine

NH_3	+ $2Cl_2$	$\rightleftharpoons$ $NHCl_2$	+ 2HCl	Reaction Equation
ammonia	+ chlorine	dichloramine	+ hydrochloric acid	Compounds involved
N: 14x1 = 14	Cl_2: 35.5x2 = 71	N: 14x1 = 14	H: 1x1 = 1	
H_3: 1x3 = 3		H: 1x1 = 1	Cl: 35.5x1 = 35.5	
		Cl_2: 35.5x2 = 71		
NH_3: 17	Cl_2: 71	$NHCl_2$: 86	HCl 36.5	Formula Weights
x1	$2Cl_2$ x2	x1	2HCl x2	No. of each Species
Totals 17	+ 142	= 86	+ 73	Total relative wts.
159 (Relative wt. of reactants)	=	159 (Relative wt. of reaction products)		
NH_3 3 hydrogen atoms		3 hydrogen atoms	$NHCl_2$ + 2HCl	
NH_3 1 nitrogen atom	=	1 nitrogen atom	$NHCl_2$	
$2Cl_2$ 4 chlorine atoms		4 chlorine atoms	$NHCl_2$ + 2HCl	

Table 1-3 Reaction Sodium Sulphate Chlorine and Water

Na_2SO_3 +	Cl_2 +	H_2O	$\rightleftharpoons$	Na_2SO_4 +	$2HCl$	
Sodium Sulphite	chlorine +	water		Sodium Sulphate +	hydrochloric acid	Reaction equation compounds
Na_2: 23x2 = 46	Cl_2:35.5 x 2 = 71	H_2: 1 x 2 = 2		Na_2: 23x2 = 46	H: 1x1 =	
S: 32x1 = 32		O: 16x1 = 16		S: 32x1 = 32	Cl: 35.5x1 = 36.5	
O_3: 16x3 = 48				O_4: 16x4 = 64		
Na_2SO_3 126	Cl_2 71	H_2O 18		Na_2SO_4 142	HCl 36.5	Formula wts.
x1	x1	x1		x1	x2	No. of each species
126	71	18		142	+ 73	Total relative wts.
215 (relative wt. of reactants)				215 (relative wt. of reaction products)		

Equations in Tables 1-2 and 1-3 demonstrate the "material balance" relationship of the reagents involved and are useful in chemical requirement calculations. However it is possible to rewrite the above sulphite - chlorine reaction in an alternate form for emphasizing other aspects of the reaction:

$$SO_3^{=} + Cl_2 + H_2O \qquad SO_4^{=} + 2H^{+} + 2Cl^{-}$$

The above reaction statement is actually more correct in stressing the ionic identities of reactants and products where the earlier reaction equation would suggest that sodium, sulphite, sulphate, hydrogen, and chloride ions actually paired together during the reaction in solution. Such ions would have only paired up again on removal from solution.

Although the latter reaction statement is more precise in showing the increase in hydrogen ion in solution (that is, a decrease in pH), it does not directly show that say 126 units (grams, pounds, tons) of Na_2SO_3 would dechlorinate 71 units (grams, pounds, tons) of chlorine. So each form of the equation can have its various uses.

Note that the second expression of the reaction has also been simplified by ignoring the presence of the sodium ion which does not take part in the reaction. The resulting negative charge contributed by the removal of the positive sodium ions from both sides of the equation is summed up to be equal for each side. A reaction equation is also not properly balanced unless the algebraic sum of positive and negative charges on each side is similarly equal.

SUBJECT:

SURFACE WATER TREATMENT

TOPIC: 2

Microbiological Considerations

OBJECTIVES:

The trainee will be able to

1. Know the types and sources of micro-organisms of interest to waterplant operation.

2. Discuss the importance of preliminary treatment for the production of a pathogen-free finished water.

3. Know the limitations of the following disinfectants in water treatment from a microbiological viewpoint:

   a) chlorine

   b) ozone

   c) iodine

   d) chlorine dioxide

4. Recognize problems caused by bacteria in distribution systems.

5. Interpret the results of bacteriological lab tests and take corrective measures as required.

MICROBIOLOGICAL CONSIDERATIONS IN WATER TREATMENT

GENERAL

Water treatment was first introduced to remove or inactivate pathogenic microorganisms in the water, thus preventing the spread of waterborne disease. Only when this goal had been achieved was it realized that further treatment stages could improve the water quality from the aspect of colour, taste, odour and iron removal, etc. A conscientiously applied treatment will also prevent the development of problems within the distribution system.

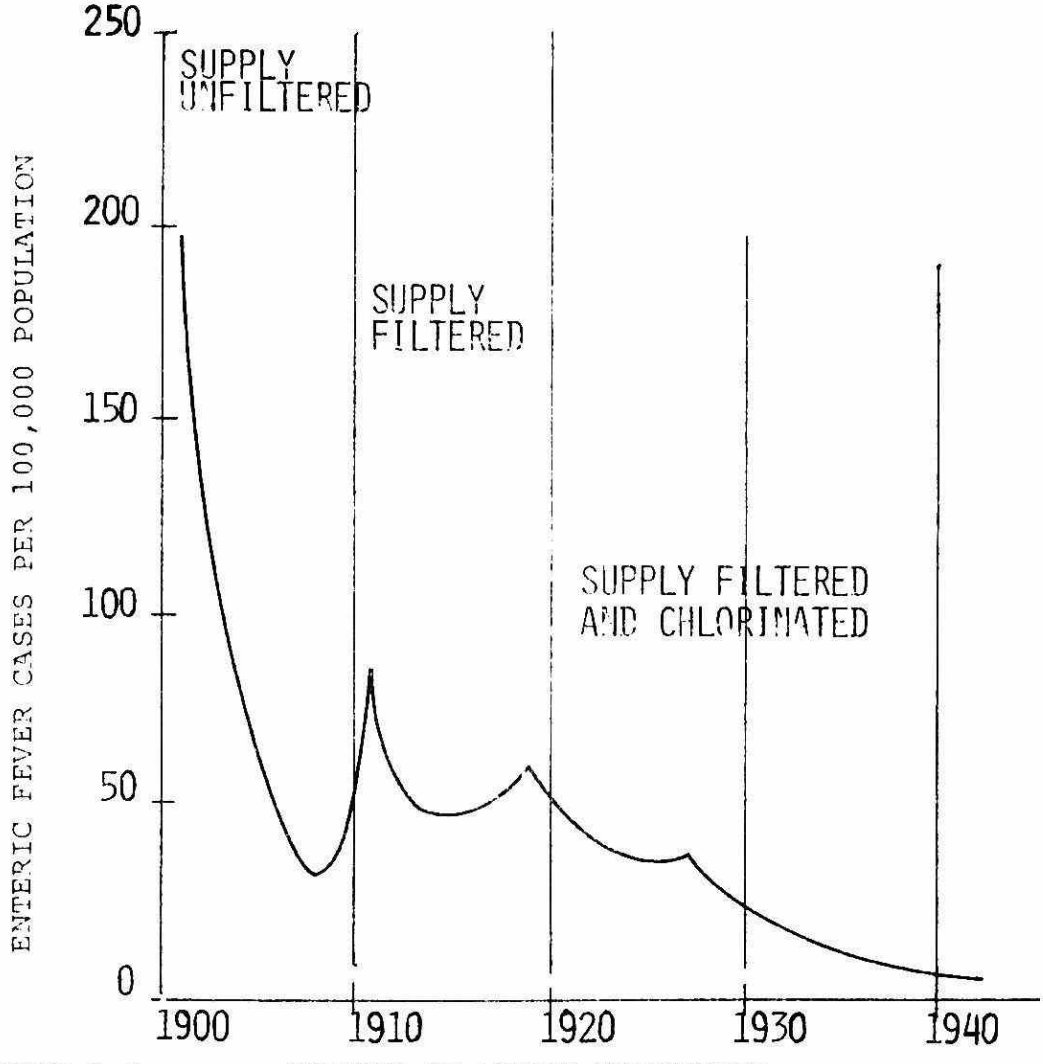


FIGURE 2-1 EFFECT OF WATER TREATMENT UPON PUBLIC HEALTH

from M. Hutchinson, Water Research Association, Tech.Memo 92, 1974

SOURCES AND TYPES OF MICROORGANISMS IN WATER

Natural water always contains some microorganisms, the so-called natural microorganisms derived from soil, air and water. If the water is polluted, it will contain the polluting microorganisms, from agricultural run-off, animals, birds, sewage effluents, tile beds and man. These polluting microorganisms are most important from a sanitary point of view, since microorganisms in this group can cause diseases in man and animals. They can be of three types:

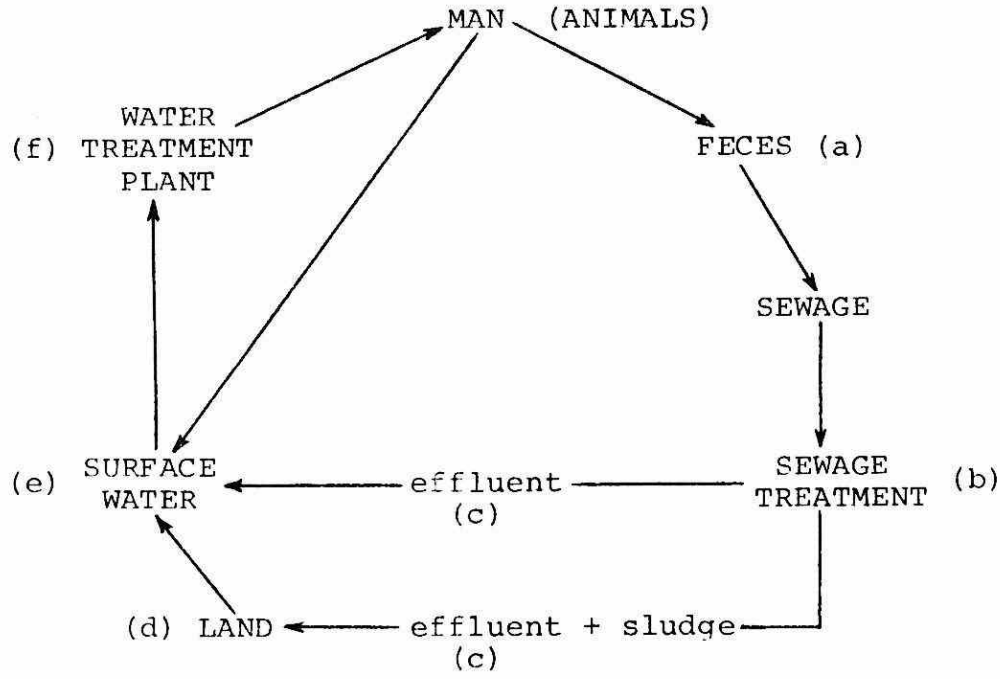
1. Bacteria: - causing diseases such as typhoid and dysentery.

2. Viruses: - these microorganisms are much smaller than bacteria; they can only grow within living cells, and therefore do not multiply outside of their animal hosts. They are, however, very resistant to environmental conditions, and in general survive much longer than pathogenic bacteria under the same conditions. Viruses are responsible for such diseases as poliomyelitis and infectious hepatitis. As far as is known, there are no natural viruses; they are always associated with an infection.

3. Parasites: - These are actually microorganisms, such as tapeworms, and amoeba. The actual organism is ordinarily not found outside its host, but the ova (egg) or cysts are passed in the feces and being highly resistant, gain access to water.

POLLUTION CYCLE

The "pollution cycle" showing the sequence of events resulting in pollution of water, may be shown diagrammatically:



Any microorganisms excreted in the feces (a) capable of multiplication in the intestinal tract, are potentially capable of causing infection via the water route. Feces reach the Water Pollution Control Plants in raw sewage along with other wastewater and storm run-off from land, etc. Sewage treatment (b) serves two main purposes:

1. Removal and Breakdown of organic matter
2. Inactivation of pathogenic microorganisms, (although this is seldom completely successful).

The sewage effluent (c) is discharged either directly to a surface water or to the land, from whence the microorganisms may reach potable water supply through seepage, percolation or run-off; Sludge (c) is normally spread on agricultural land also. Percolation of effluent through the soil (d) can remove large numbers of microorganisms, but the extent of removal depends on the nature of the soil, rainfall, organic

quality of the effluent, etc., and some may reach aquifers used for potable water. Under some conditions, for example, virus has been detected after 20-30 feet of percolation through soil. Surface water from an urban area receiving sewage effluents direct (e) is probably the least pure water from a microbiological stand-point. It is the responsibility of the water treatment plant (f) to ensure that safe, potable water is produced from the source water by ensuring inactivation of the viruses and other disease-producing microorganisms. See Appendix A for bacteriological test procedures.

INDICATORS OF RAW WATER POLLUTION

It is the operator's job to know the extent of the raw water pollution but it is difficult to detect the harmful (pathogenic) organisms in the water because they are present in relatively small numbers, being excreted by only a few infected individuals in any one community. Assessment of the degree of fecal pollution of a surface or ground water is therefore usually measured by presence of an "indicator" organism. Indicator organisms - coliforms, fecal streptococci, clostridium perfringens, etc. - are excreted by every person, are present in much larger numbers and are relatively easy to detect; they are harmless organisms which make up part of the natural flora of the intestine of man and animals. Where fecal coliforms or another selected indicator organism can be found in a water sample, it is assumed that the water has been contaminated by fecal material and therefore, may also contain organisms capable of causing intestinal disease. However, the indicator organisms are bacteria, and are thus physically different from viruses; these latter tend to survive much longer in water and are much more resistant to disinfection procedures. Therefore, the absence of an indicator bacterium in a sample may not necessarily indicate an absence of viruses, i.e. the coliform indicator test is not really an adequate indicator test for the enteric viruses. Viruses have been isolated in instances where the coliform standard was met.

It has been calculated that the density of enteric viruses in sewage is probably 500 units per 100 ml, and in polluted surface water 1 unit per 100 ml (Clarke, Kabler & Chang, Ad. in Water Poll. Res., Proc. Intl. Conf. London 1962 Pergomon Press. p. 523-532). Since 1 virus unit is capable of causing infection in man, a glassful of polluted surface water would theoretically contain an infecting dose of virus. This points out one of the many problems involved with viruses in water; although they may be present in very small numbers, they can pose a considerable threat to human health.

CONTAMINATION LIMITS

Water used by a community for consumption and other domestic purposes should be piped and adequately treated to render it free from disease-producing organisms. It is reasonably certain that disease organisms are absent if no pollution indicator bacteria are found during examinations of 100 ml samples. Hazardous quality indicator organisms which include the fecal coliform and fecal streptococcus groups and pathogenic organisms such as *Pseudomonas aeruginosa* and *Staphylococcus aureus* should be completely absent from drinking water. It should also be relatively free from coliforms, *Aeromonas* bacteria and *Clostridium perfringens*, which indicate poor water quality or deteriorated conditions in the water treatment plant or distribution system. *When a minimum of two distribution system samples of 100 ml are examined each week, no sample should show the presence of fecal coliforms or fecal streptococci, or pathogens, such as Pseudomonas aeruginosa and Staphylococcus aureus, or a density of five or more coliform bacteria per 100 ml.*

If any of these limits are exceeded, immediate collection and analysis of special samples from the affected and adjacent locations should be initiated, together with an investigation by the operating authority of the cause of their presence.

If the results of these special samples also exceed the above limits immediate chlorination should take place to insure a total chlorine residual of 0.5 mg/l or a free chlorine residual of 0.2 mg/l at the end of the distribution system; and if circumstances warrant, the immediate issuance of a boil-water order should be made. Thorough resampling and analysis of the entire water system should immediately begin and continue until the limits described above are not exceeded.

When coliform bacteria are present at levels below 5 per 100 ml, they should not be detected in more than 5% of the monthly samples, nor should such organisms as Aeromonas or Clostridium perfringens be detected in more than 10% of the monthly samples. If the limits are exceeded, and inspection of the water works and distribution system should take place along withsufficient special samples to determine the cause for the limits being exceeded. A special sampling program should continue until acceptable limits are obtained.

Special samples collected as the result of an adverse bacteriological sample shall be considered additional to the total number required to be collected by a municipality for assessment of its water quality.

INTERPRETATION OF RESULTS

The interpretation of the routine bacteriological reports is perhaps the most important aspect. Results are usually expressed as the number of bacteria present per 100 ml of sample. P/A tests are reported using the words "present" or "absent".

Water delivered to the consumer ("finished" water) is expected to conform to certain limits and objectives. Where some bacteria reach undesirable levels, the pattern of the results can sometimes be used to decide the corrective action to be taken. See Table 2-1.

Coliforms are found in the intestine, but can also occur on soils and vegetation. *Fecal coliforms* form a sub-group within total coliforms but, as indicated by their name, are found *only* in human and animal fecal waste; since they die out more rapidly than coliforms, their presence should be considered as a sure indication of recent fecal pollution, calling for immediate action. The repeated presence of coliforms, in the absence of fecal coliforms, may indicate the growth of these bacteria on organic materials in the pipe or on debris, and investigation should be made into possible sources.

Fecal Streptococci (enterococci) are normally found only in situations where fecal pollution has occurred. They are used as indicators of pollution in the same way as fecal coliforms, and their isolation is especially useful where coliforms are present, but fecal coliforms cannot be found. They are more resistant to chlorination than coliforms and tend to survive longer. Absence of these bacteria shows that disinfection has been adequate.

Pseudomonas aeruginosa is a potential pathogen which occurs in sewage. Since it shows some resistance to chlorination, there is growing pressure to include a test for it and other fluorescent pseudomonads, in routine examination of potable water. As with the fecal streptococci, the appearance of pseudomonads may indicate that the chlorine dosage is too low and a correction is necessary.

Clostridia are a group of organisms which are again mainly used as indicators of fecal pollution, since they are present in sewage and manure. However, these organisms produce very resistant bodies called spores; on account of these, the bacteria can survive in water long after all other indicator organisms have disappeared. These indicators are useful in water supplies that are not sampled frequently. In these cases, chance sampling may give good coliform results, but the water could be dangerously contaminated at intervals in between. Clostridia would probably be isolated

in these circumstances and would indicate a need for closer surveillance. The spores are not destroyed by normal chlorination practices, and repeated positive clostridial tests show that treatment was inadequate before final chlorination (e.g. in filtration).

Treating water supplies properly and effectively not only ensures freedom from pathogenic organisms, but also yields beneficial side effects. A finished water entering the distribution system with a turbidity of 1 unit or less and chlorine residual of 0.3 ppm will meet bacteriological standards, and organic material and debris will not enter the lines. *Every effort should be made to achieve these levels.* Where debris enters the lines, bacterial growth and slime formation can occur, with taste and odour and red water problems developing. Correct pH control and/or treatment for the presence of iron will prevent the deposit of rust and iron materials in the line.

A conscientiously applied treatment will prevent the transmission of water-borne disease, deliver to the consumer a clear, palatable product, and maintain a trouble-free system.

Table 2-1 BACTERIA INDICATORS OF SEWAGE CONTAMINATION IN WATER TREATMENT

	Total	Fecal Coliform	Fecal Streptococci	Pseudomonas Aeruginosa	Fluorescent Pseudomonads	Clostridia
Test	MF	MF	MF or P/A	P/A	P/A	P/A
Reported	Numbers/ML	Numbers/ML	Numbers/ML	+ or -	+ or -	+ or -
Maximum Allowable Limit	5/100 ml in monthly samples	Absent	Absent	Absent	Few	10% samples positive
Source	Sewage, Soil Vegetation	Fresh sewage	Sewage	Sewage	Soil, Water Sewage	Old Sewage Manure
Indication	a) Possible contamination with sewage	Definite contamination with fresh sewage	Definite contamination with sewage	Improper treatment	Improper treatment	Improper treatment prior to chlorination
	b) Improper treatment		Improper treatment			
	c) Growth in system					

STAGES IN WATER TREATMENT

GENERAL

When guidelines were first drawn up for water supplies, one of the first requirements was that the source water be free of contamination. However, such sources of water are becoming more difficult to find, because of greater urbanisation, a greater demand for water and increasing pollutional loads. Since the source water may possibly be contaminated, some form of treatment is normally applied to public water supplies. In some cases it is felt that the source quality is such that it is necessary to apply some type of disinfection procedure only. In all other cases the preliminary treatment of the water is undertaken basically to prepare the water for the disinfection step; the non-operation or faulty operation of any preliminary process will result in the disinfection process being less efficient.

The importance of complete treatment, even to what may be assumed to be a fairly safe supply, was indicated by a study in 1966. In a city which had a reasonable quality source of supply, about one half of the supply received complete treatment, whereas the other half received disinfection (chlorination) only. Infectious hepatitis rates were determined in the communities served by each supply. The rate in the population served by the supply which was chlorinated only was higher than that in the population receiving fully treated water. Introduction of full treatment to both supplies resulted in an equalization of infection rates (Gaylor, Eagen, Smith & Coene. AJPH.56. 2093-2103. 1966) (See Figure 2-2).

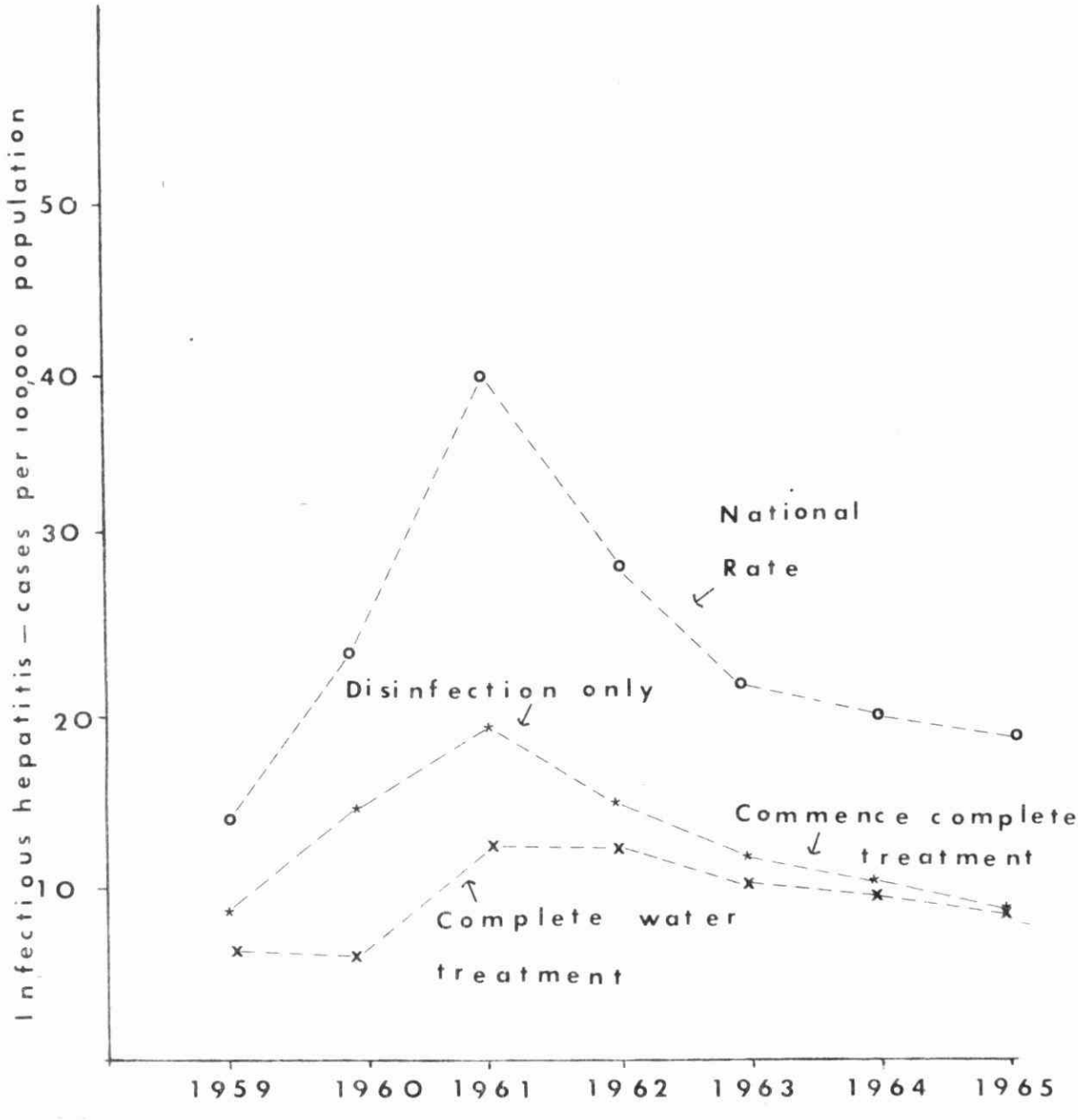


Figure 2-2 INFECTIOUS HEPATITIS
COMPLETE TREATMENT vs DISINFECTION ONLY

STORAGE

Prolonged storage or impoundment of water prior to treatment, for a period of 10 days or more, would result in the reduction of the numbers of pathogenic bacteria, but would have little effect on either parasites or viruses. It effects considerable reduction in the amount of suspended matter, but under certain conditions may allow the multiplication of unwanted, nuisance organisms, such as algae or actinomycetes (bacteria-like organisms responsible for the production of earthy-musty odours in water. Impoundments tend to ease the deteriorating effects of poor quality inflows (due to run-off, etc.) and consequently the outflow quality is fairly uniform. The practice of impoundment is not common to North America, with the possible exception of the South West USA.

The normal storage time available in water treatment plants would cause little significant reduction in any potentially pathogenic organism.

FILTRATION

Slow Sand Filtration

Slow sand filtration is one of the earliest and most effective methods of water purification. The effective size of the sand is normally 0.2-0.5 mm, with a uniformity coefficient of between 1.5 and 2.5. The rate of filtration is about 0.0086 gals/min/sq.ft., in the 24 hours immediately following cleaning, reaching an average flow of 0.035 gals/min/sq.ft. during normal operation.

The size of the sand and the slow rate of filtration does not allow penetration of the sand by particulate matter and microorganisms, and a zoogloeal layer (a jelly-like mass of organic matter, protozoa and microorganisms) forms on top of the filter. Upon backwash, much of this growth remains attached to the sand particles, and eventually the top layer of sand must be skimmed off mechanically.

Parasites and bacteria are effectively removed if the rate is carefully controlled, more by the activity in the zoogloeal layer than by actual filtration. For viruses, removal tends to be erratic until the filtration rate approaches 0.008 gals/min/sq.ft., with a minimum 3 feet depth of sand.

The Metro Toronto Island WTP was the last slow sand filtration plant in Ontario, and was converted to rapid sand filtration several years ago.

Rapid Sand Filtration

Rapid sand filtration is carried out at a rate of about 1.7 gals/min/sq.ft., with sand of an effective size range of 0.5-1.0 mm, and a uniformity coefficient of about 1.5. An improvement in rapid filtration was brought about by the introduction of anthracite and dual media filtration, which enabled more rapid filtration rates to be used.

Rapid filtration through sand or dual media filters, without the aid of a coagulant such as alum, will not remove viruses at all, and will allow the passage of many of the bacteria. Although the effluent turbidity may be below the objective of 1 Jtu (Ftu), organic matter and microorganisms may pass through, interfering with the disinfection process and entering the distribution system.

Rapid filtration is therefore normally used in conjunction with some form of coagulation process. To obtain reasonable efficiency and economy, it is vital that the preliminary coagulation and settling of the water is properly controlled. Alum sulphate and ferric chloride are the most efficient coagulants for both virus removal and the removal of other contaminants, such as turbidity, etc. Cationic polyelectrolytes may allow the dose of coagulant to be reduced and yet achieve the same degree of contaminant removal. It also helps to form a denser, faster settling floc. Coagulant dosage, with settling followed by rapid sand filtration can result in virus removals of 98% under optimal conditions.

Direct filtration, where the coagulated water is applied directly to the top of the filter, provided it is carried out efficiently with good floc formation, is also effective in virus removal.

In both forms of rapid filtration, floc breakthrough is accompanied by the presence of large numbers of viruses in the effluent. The occurrence of floc breakthrough depends primarily on floc strength. Other conditions, such as chemical dosages, floc carry-over, filter media and filtration rate also play an important role in filter breakthrough. If a clear water is being treated, but no coagulant or insufficient coagulant has been added, virus breakthrough can occur with little or no increase in the turbidity of the filter effluent.

Viruses remain viable on the floc particles, and live viruses can be recovered merely by raising the pH of the floc suspension.

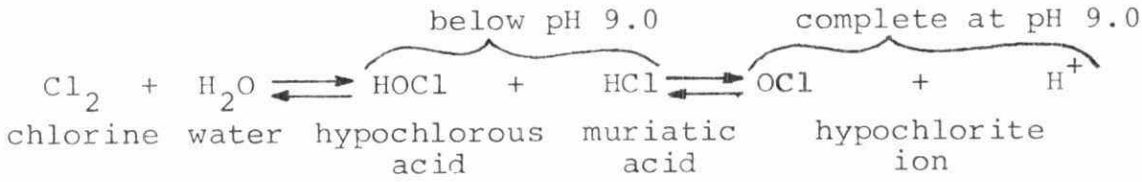
DISINFECTION

The treatment stages prior to disinfection are essentially preparing the water for the disinfection process; poorly prepared waters cannot be efficiently disinfected. This is illustrated in a study where an emergency supply of poor quality water was used to supplement a well supply; although the recommended chlorine levels had been applied to the combined water, an outbreak of infectious hepatitis occurred (Poskanzer & Beadenkopf Pub. Hlth. Reps. 76 745-751 1961). The suspended matter and organic load contributed by the poorer quality combined supply, had rendered the chlorination stage ineffective.

Destruction of pathogenic bacteria in water supplies is brought about by treatment with a germicidal substance. The following are the substances most commonly used.

Chlorine

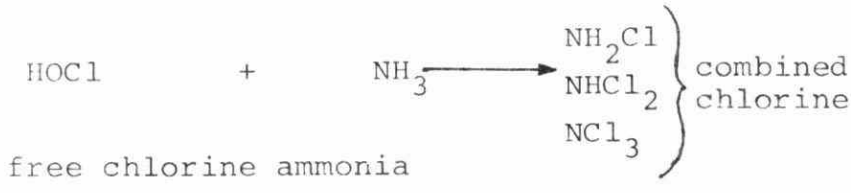
When chlorine is added to water, HOCl (hypochlorous acid) is formed; this further dissociates into H^+ and OCl^-, a reaction which is completed at pH 9.0 .....



Above pH 7.5 hypochlorite ions predominate and since hypochlorous acid is a much more powerful disinfectant than hypochlorite, (although both are technically "free chlorine") pH control during disinfection becomes very important. About ten times as much hypochlorite is required than hypochlorous acid, to inactivate enteric viruses in a thirty minute retention time. This is probably due to the inability of hypochlorite to penetrate the protein coat of the virus. (R. Culp, JWWA. 66. (12) 699-703. 1974).

Free chlorine is an extremely rapid bactericide, but viruses show a varying resistance to it. It is generally agreed, however, that under practical conditions, where the pH is below 8.0, and the temperature above $4^{\circ}C$, a 0.2 - 0.3 ppm free residual would result in a 99.99% destruction of viruses in 30 minutes. At pH above 8.0 but below 9.0, a 50% increase in either chlorine residual or contact time would be required for the same degree of inactivation.

Where ammonia and/or amino compounds are present, chloramines are formed (combined chlorine) .....



Combined chlorine is reasonably effective against bacteria, but about 50 times less effective against viruses than hypochlorous acid.

An increase in organic matter, whether suspended or dissolved, also affects disinfection efficiency. When organic matter is added to a virus suspension, even though sufficient chlorine is added to meet the additional chlorine demand thus created, 10 to 15 times as much chlorine is required to achieve disinfection as compared to the same suspension without the organic matter (Trask, Melnick & Wenner. Am. J. Hyg. 41. 30-40. 1945).

This fact re-emphasizes the importance of the treatment stages prior to disinfection; even where raw water turbidity is too low for conventional flocculation, in-filter flocculation (direct filtration) should be used to render the water suitable for disinfection.

Recently it has been found that 12°C is a critical temperature in the disinfection process using chlorine. Below this temperature, because of the decrease in the metabolic activity of the bacteria disinfection tends to be less efficient. (Reid & Carlson. Proc. Am. Soc. Civil Eng. 100. #EE2. J. Environ. Eng. Div. 1974). It requires three times longer contact with hypochlorous acid for the same inactivation at 2-5°C as compared to 20-25°C.

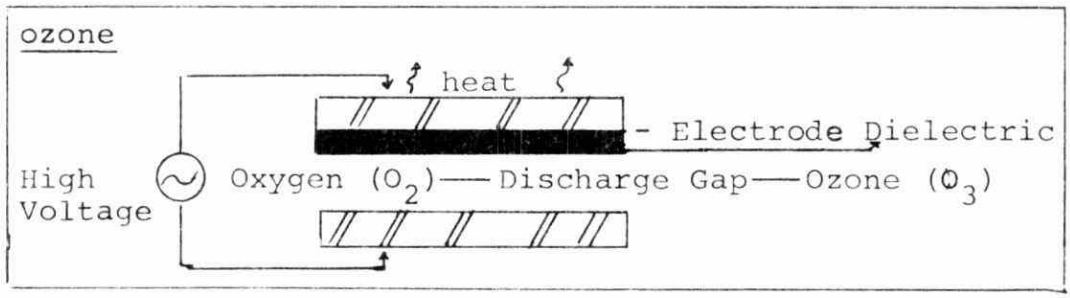
Thus the time required for disinfection with chlorine increases with - - - - - - -

-Increase in pH
-Decrease in free chlorine concentration
-Increase in organic matter
-Decrease in temperature

NO CONDITIONS OF DOSAGE AND CONTACT SHOULD BE ACCEPTED UNLESS THEY ARE SHOWN TO PRODUCE A WATER WHICH MEETS BACTERIOLOGICAL STANDARDS.

Ozone

Ozone, which has one and a half times the oxidizing efficiency of chlorine, is regarded as more efficient in the destruction of viruses than chlorine, but evidence is accumulating that it may not be as efficient in the destruction of bacterial pathogens. Ozone is usually formed by silent electric discharge applied to oxygen.



Ozone is not as easy to apply to the water as chlorine, since it is only sparingly soluble and therefore difficult to disperse through the water to maintain the required level. Maintenance of the equipment to retain peak efficiency of ozone production also appears to be a problem, and it is considerably more costly. It has found application in areas where its use results in a side benefit, such as colour removal.

An ozone residual of 0.5 ppm for 5 minutes is normally regarded as adequate for disinfection. Ozone concentrations may be measured by the iodometric method using the starch/ iodide end point.

With ozone, no residual remains in the water during delivery to the distribution system, although it does oxidize much of the organic matter upon which nuisance organisms may grow. In order to limit the growth of such organisms in the system, a chlorine residual should be applied to the ozonated water before it leaves the plant.

Iodine

Iodine is a reasonably good all-round disinfectant, 4-5 times less efficient than hypochlorous acid. It can be more readily applied to small supplies without the need for complex dosing equipment.

$$H_2O + I_2 \rightleftharpoons I^- + H^+ + HOI$$

iodine — iodine ion — hydrogen ion — hypoiodous acid

Iodine has not gained wide acceptance except for emergency field systems.

Chlorine Dioxide

Chlorine dioxide is less potent as a germicide than chlorine, but it has the advantage of being unaffected by high pH and amino compounds. It is used for taste and odour control where phenols are present, or in waters with a high ammonia content.

$$\underset{\text{sodium chlorite}}{2\ NaClO_2} + \underset{\text{chlorine}}{Cl_2} \longrightarrow \underset{\text{chlorine dioxide}}{2ClO_2} + \underset{\text{sodium chloride}}{2NaCl}$$

The equipment and chemicals required for its production are outlined in the water treatment chemicals section.

The residual generated by chlorine dioxide is maintained further into the distribution system than that of chlorine alone, and it can be applied at high dosages without complaints occurring in the vicinity of the plant. The residual may be measured by the orthotolidene method, and is a measure of total residual; the colour developed is equal to 1/5 that of the available chlorine, and thus the reading times five, represents the total available chlorine.

MEASUREMENT OF DISINFECTION EFFICIENCY

The standard measure of the efficiency of disinfection is the coliform index. This index, used as the minimum standard, will not ensure the safety of the water with respect to viruses (Chang. Bull. Wld. Hlth. Org. 38 401-414 1968). Furthermore, the rule of thumb practice of chlorinating a level of 1-2 mg per litre will not satisfy the needs for inactivation of pathogenic organisms (editorial p. 700 JWPCF April 1969), when other factors are uncontrolled or are ignored. The addition of chlorine or other bactericidal agents is not a cure-all; when a source water is sufficiently heavily contaminated, bacteria and viruses embedded in organic matter are not inactivated even in the presence of free available chlorine. The same situation applies if floc or organic particles have broken through during filtration. Other disinfecting agents are affected similarly.

There is research continuing to develop a better indicator of disinfection efficiency, preferably where the results are immediately available; none has received universal approval as yet.

DISTRIBUTION SYSTEM EFFECTS

The production of a high quality water will have beneficial side effects on the distribution system. Where organic matter or breakthrough floc is allowed to enter the distribution system, it eventually becomes deposited in the piping providing nutrients for bacteria. The maintenance of a residual in the lines limits the growth of those bacteria surviving the disinfection procedure. However, this residual is rapidly destroyed where organic matter has accumulated, and bacterial growth can occur. Slime growths and low DO are produced with accompanying tastes and odours and the slime may slough off and reach consumers' taps.

If bacterial multiplication does occur to any extent (total count in excess of 500-1000 organisms per ml), the bacteria produced can interfere with the coliform test; the growth of coliform bacteria is suppressed, and potentially dangerous water may thereby appear to meet coliform standards.

Sulphate-reducing and iron bacteria may colonise the deteriorating systems causing corrosion, red water and impedance of flow. In severely affected lines, foam swabbing is probably the only available form of treatment.

CONCLUSIONS

At present there is no clear-cut evidence of the regular transmission of pathogenic organisms by treated water supplies; however, the number of such episodes during a period of breakdown of equipment, or when emergency supplies must be used, indicates the importance of complete, properly applied treatment at all times. In the USA, as Figure 2-3 shows, about 29% of thewaterborne disease outbreaks have been attributable to defects in treatment or in the distribution system, accounting for 26% of the total cases of illness.

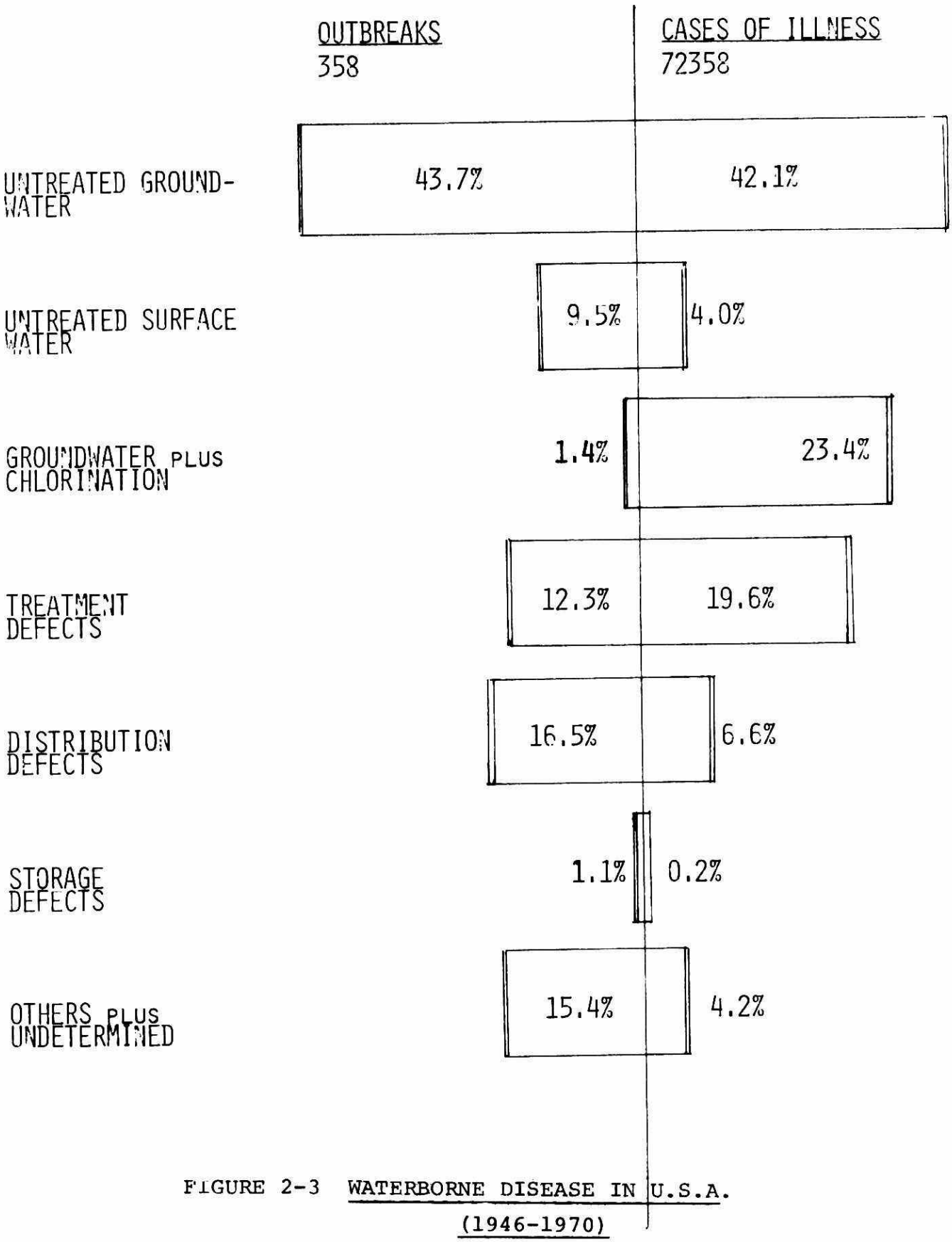


FIGURE 2-3 WATERBORNE DISEASE IN U.S.A. (1946-1970)

Of those resulting from inadequate treatment (Table 2-2) 70% were due to deficiencies in chlorination; failure of chlorination equipment accounted for 27% of the outbreaks and failure of some other treatment stage resulted in 3% of the recorded outbreaks.

TABLE 2-2

CAUSES OF WATERBORNE DISEASE - INADEQUATE TREATMENT - USA 1946 - 1970

	% Outbreaks	% Cases
Inadequate chlorination	70	78
- insufficient dose		
- insufficient contact		
Failure of chlorination	27	21
Failure of other treatment	3	1
- resulting in excess chlorine demand		
- resulting in excessive turbidity		

These figures, it must be emphasized, have been obtained from records of reported disease outbreaks. Many other isolated cases of enteric disease probably occur which are not sufficiently serious to result in a report being registered. This kind of low level transmission is almost impossible to detect and probably represents the situation for many of the pathogenic viruses; many infections with viruses result in only mild, short-lived disturbances which would not be recorded as disease outbreaks.

With water sources subjected to steadily increased pollution, it must be pointed out that problems may develop in the future if current practices of treatment and quality control are continued. Data from the United States, given in Table 2-3 collected in a survey carried out in 1970, show that only 10% of the systems surveyed met US standards of quality and number of samples submitted for analysis, 85% of the systems were submitting insufficient samples and 12% exceeded the coliform limit.

TABLE 2-3

POPULATION SIZE AND BACTERIAL QUALITY OF WATER (USA 1970)

POPULATION (X 1,000)	% SYSTEMS			% POPULATION EXPOSED TO COLIFORM
	MET STANDARDS ON: (I) NO SAMPLES (II) QUALITY	INSUFFICIENT SAMPLES	EXCEEDED COLIFORM LIMIT	
0.5	4	94	18	15
0.5 - 5	18	74	10	8
5 - 10	12	83	7	7
10 - 25	10	85	9	7
25 - 50	3	92	3	3
50 -100	12	88	6	6
100	36	64	0	0
OVERALL	10	85	12	2

Hudson (JAWWA 54. 1265-1272. 1972) emphasized the need to strive toward high quality goals on the basis of several criteria. In a discussion of this paper, Woodward stated that standards for drinking water are to be used in judging the quality of water reaching the consumer and this is often overlooked. There is invariably an increase of turbidity and coliform organism numbers in the distribution system, and thus water plant operators should not be satisfied with merely meeting the standards in plant effluent. The water treatment plants are the major line of defence against the introduction of pathogenic organisms into the water distribution system and thence the population. The absolute necessity of constant vigilance in careful, complete plant operation cannot be emphasized enough.

SUMMARY

The responsibilities of potable water supply authorities serve as a summary of the topics covered and are:-

1. Protect sources from excessive pollution.
2. Properly design, install and operate water treatment processes.
3. Provide spare capacity in case of emergency.
4. Prevent subsequent risk of contamination or deterioration in quality during distribution.
5. Bacteriological checks should be carried out on a regular basis as part of the process control.

REFERENCES

The following references are provided for those who may wish to add to their library. These texts are not specifically confined to the bacteriological section but contain information applicable to any section of the course.

1. Water Quality and Treatment. A Handbook of Public Water Supplies. 3rd Edition. Prepared by the American Water Works Association, Inc., McGraw-Hill, Book Company.

2. Water Treatment and Examination. Edited by W. S. Holden, 1970. Published by Williams & Wilkins.

3. Ministry of Environment Drinking Water Objective, 1976.

BACTERIOLOGICAL TEST PROCEDURES

Samples submitted for bacteriological analysis may be tested by any one or all the following methods:

1. Most Probable Number (MPN)
2. Membrane Filtration (MF)
3. Presence/Absence Test (P/A)

Most Probable Number (MPN)

This method has largely been abandoned now, except for samples that may be too turbid for membrane filtration.

For estimation of fecal coliforms, the same procedure is followed, except that the incubation temperature is 45°C.

Five 10 ml, five 1 ml. and five 0.1 ml samples of the water to be tested are inoculated into lactose broth medium, containing an inverted tube; following incubation at 35°C for 48 hours, the number of positive tubes (acid and gas formation) is recorded. The results are applied to statistical tables from which the number of coliforms per 100 ml. of original sample may be determined.

Membrane Filtration (MF)

This is now the standard method of analysis used by most laboratories. One 50 ml. sample of the water is filtered under vacuum through a membrane filter (porosity 0.45μ); the filter is placed on an absorbent pad soaked in special medium (m-Endo broth) in a culture dish. After 18^{+2}_{-} hours incubation at 35°C, colonies with a greenish metallic sheen are counted as coliform organisms and the number present in 100 ml or original sample can be calculated.

Fecal coliforms can be counted by filtering a further 50 ml of the water sample through another similar membrane and incubating the filter with m-FC medium on the pad at 45.5°C. Blue colonies (fecal coliforms) are then counted.

Fecal streptococci are counted after filtration of further 50 ml, followed by incubation of the filter on yet another medium (m-Enterococcus) at 35°C for 18-24 hours. Pink/red colonies are counted to give the number of fecal streptococci in the original sample.

Presence/Absence Test (P/A)

A 50 ml sample of water is added to lactose broth medium, containing an inverted tube and incubated at 35°C. From 18-24 hours onward, several reactions are possible:

1. No change - the bottle is discarded after five days.
2. Acid production (shown by a yellow colour) - could indicate the presence of Pseudomonas, fecal streptococcus or Clostridium; the contents of the bottle are subjected to confirmatory tests.
3. Acid and gas production (yellow colour and gas bubble in the tube) - coliforms and/or fecal coliforms probably present, plus any or all of the microorganisms in 2 above. The bottle contents are subjected to various confirmatory tests.

(This method does not give number of indicator organisms but does show their presence or absence.)

SUBJECT:

SURFACE WATER TREATMENT OPERATION

TOPIC: 3

Coagulation
- Cold Weather Operation
- Algae Problems

OBJECTIVES:

The trainee will be able to

1. Recall:
   a) The types of suspended matter removed by water treatment plants.
   b) The forces acting upon the suspended particles in solution.
   c) The chemicals required for coagulation.
   d) The chemical reaction taking place in such removal.
2. Recognize the problems associated with cold weather operation.
3. Recall the advantages of using:
   a) activated silica
   b) polymers

   as a coagulation aid for cold water.
4. Recognize the problems associated with algae.
5. Take measures to prevent the control problems due to algae.

COAGULATION

REVIEW

In almost all water treatment plants in Ontario, one of the primary functions in producing a potable water is to remove one or more of three types of suspended matter. This matter includes:

1. Turbidity - loosely defined as the suspended matter in water giving the water a cloudy appearance and having the ability to deflect light. The units of measurement include:

   a) Jtu - Jackson turbidity units

   b) Ftu - Formazin turbidity units

   c) Ntu - Nephelometric turbidity units

2. Colour - made up of complex mixtures of organic compounds generally present in the colloidal state.

   The units of measurement in Ontario are generally given on a Hazen scale.

3. Algae - a form of plant life abounding in surface water. For most waterworks travelling screens remove the large pieces of algae and the algae that cause difficulties are microscopic.

   The units of measuring algae include pieces/ml and Areal Standard Units (Asu/ml).

Forces on Particles

The small colloid particles, whether they are organic or inorganic, are subjected to several forces in solution.

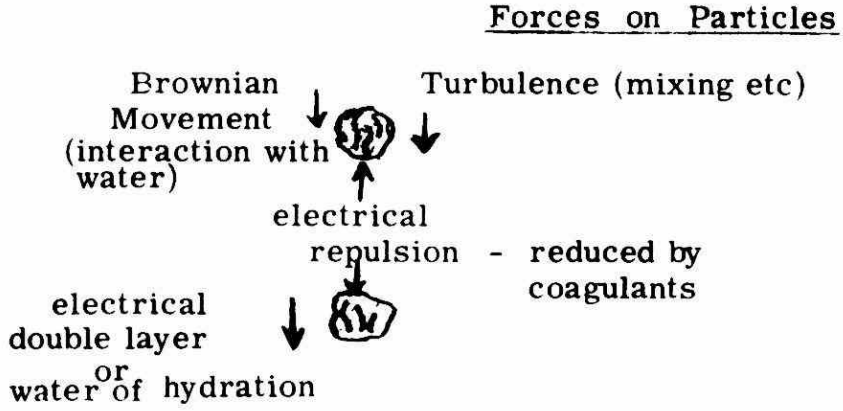
1. Brownian Movement - The particles are bombarded by water molecules which result in a movement best described as being erratic.

2. Turbulence - The particles are subjected to forces due to the movement within the water either due to mechanical mixing or the flow pattern of the water.

3. Electrical Repulsion - The particles of like charges repel one another.

4. Electrical Double Layer (Water of Hydration) This is the repulsive force that is discussed in detail in the zeta potential section.

All these forces lead to movement of the particles relative to one another as shown below.


Forces on Particles
Brownian Movement (interaction with water)
Turbulence (mixing etc)
electrical repulsion - reduced by coagulants
electrical double layer or water of hydration

The size range of these and other common types of suspended matter are illustrated in Figure 3-1. Virus particles, discussed more fully in the Microbiological Section, are the smallest particles that have to be removed in the water plant. Algae particles ranging up to 700 microns can be present in sufficient numbers to disrupt the normal water treatment process.

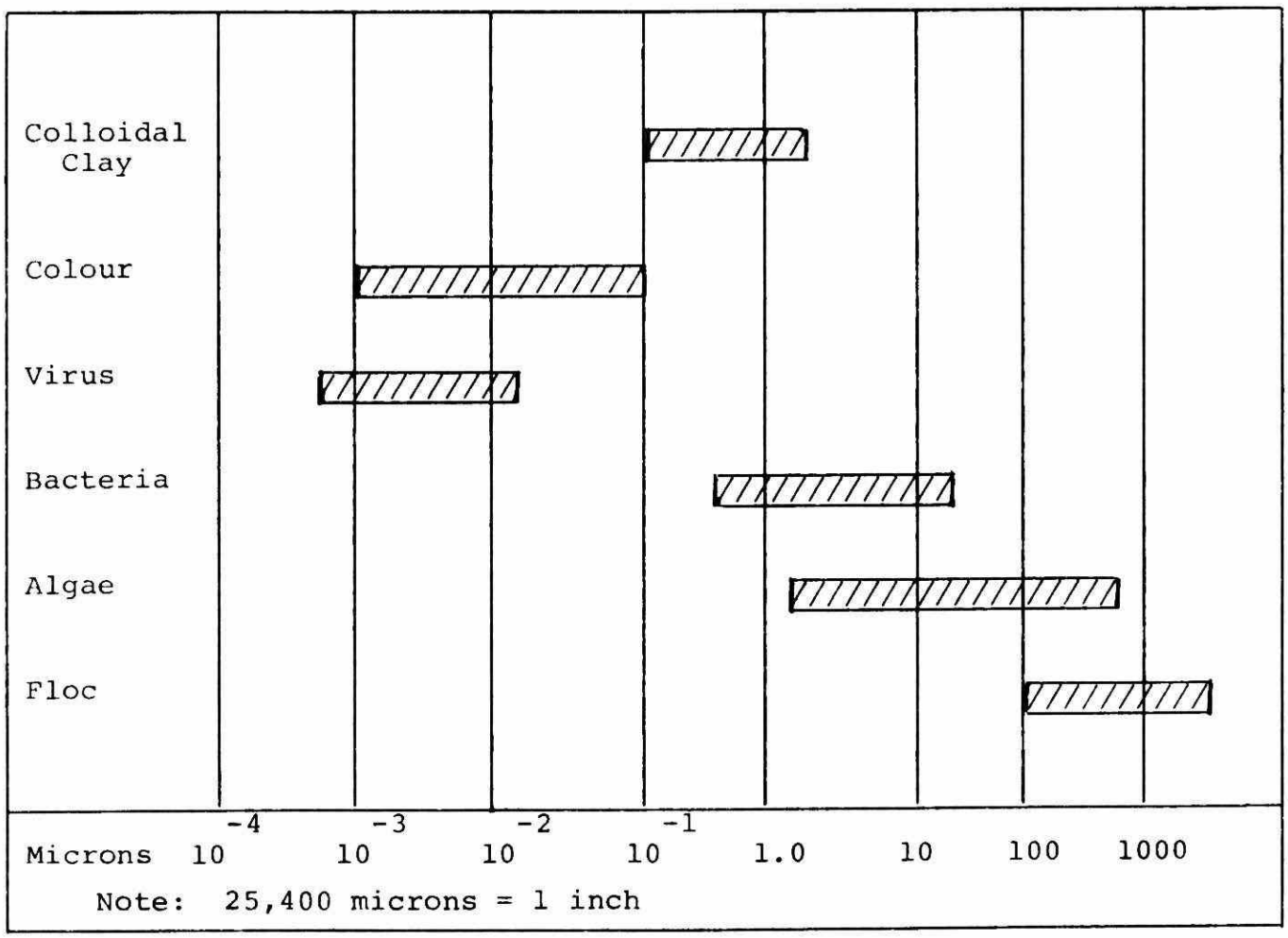


Figure 3-1 SIZE RANGE OF VARIOUS TYPES OF SUSPENDED SOLIDS

Particle Forces and Zeta Potential

Hydrophobic (water hating) particles suspended in water carry electrical charges at their surface. For most particles found in Ontario's waterways, the charge is usually negative. The charges may arise through a number of ways and means, e.g. adsorption of ions from the water or ionization of compounds on the particle surface.

Each particle suspended in a liquid should be thought of as an entity consisting of several components. The surface of the particle contains negatively charged ions. Because of this, cations, positively charged particles, are attracted to the particle surface. As a result, the particle is surrounded by a layer of water containing ions bound to the particle. This bound-water layer remains attached to the particle as it moves through the liquid. The layer is very thin relative to the particle diameter. From the edge of this layer to the bulk of the liquid solution there is a diffuse layer of ions. The strong attraction of the particle on cations decreases through the bound-water layer and the diffuse layer as the distance from the particle is increased.

The potential difference between the point where the bound-water layer ends and the bulk solution begins is the Zeta Potential (Figure 3-2).

The overall effect of the existence of electrical double layers around particles is to prevent the particles from approaching one another. As a result they remain stable in solution for a long period of time and settling of colloid particles becomes impractical due to the time factor.

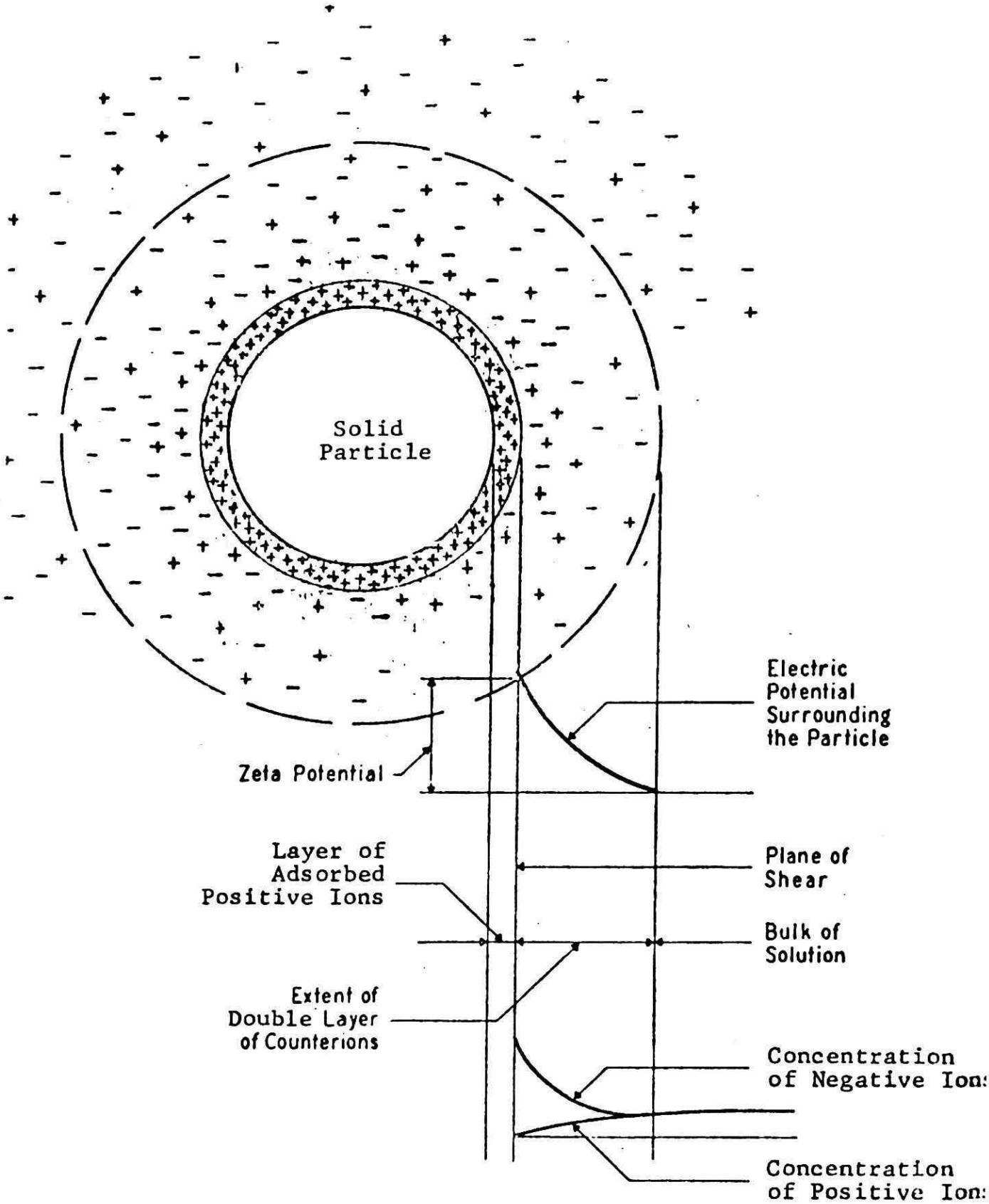


Figure 3-2 CONCEPT OF THE ZETA POTENTIAL

(from Riddick 1968)

When coagulants are added to solution and the particles are partially destabilized, the zeta potential decreases. Experimental evidence indicates that coagulation is often complete when the zeta potential is still negative (-5 to -10 mv) Figure 3-3. The reason that coagulation takes place before the zeta potential reaches zero is that the coagulants reduce the double layer thickness to such an extent that interparticle reaction can take place.

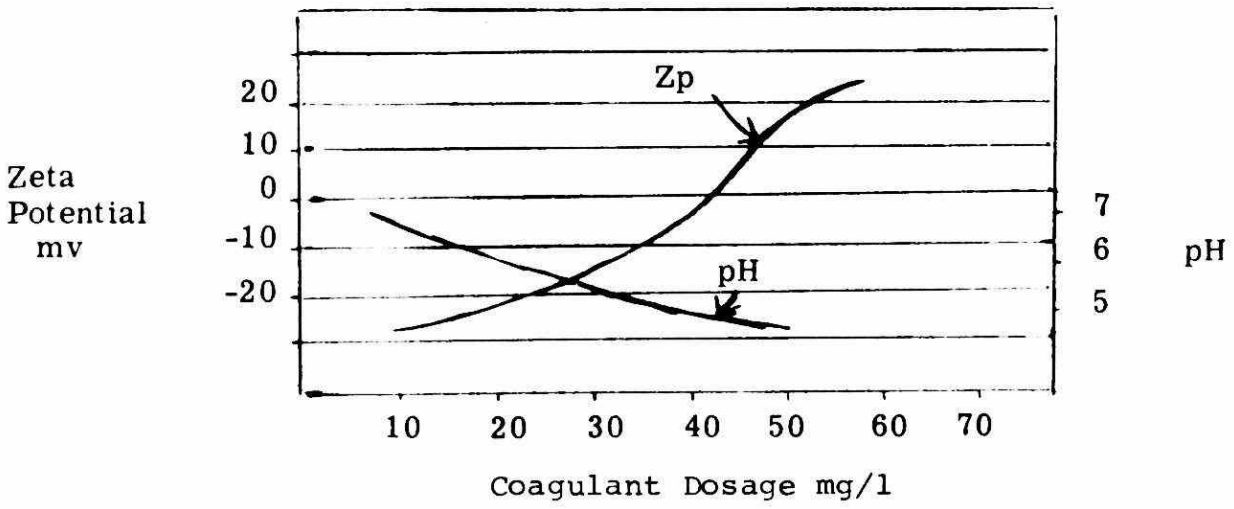


Figure 3-3 Zeta Potential & pH vs Coagulant Dosage

It is to be noted that as the alum dosage is increased the zeta potential increases until it becomes a positive value. The particles that once repelled each other because of like negative charges are now repelled from one another because they are like positive charges. If this takes place in a water plant, a disruption of the coagulation, flocculation and filtration processes takes place.

In summary, to operate the plant successfully, the optimum chemical dosage(s) which bring the zeta potential into the optimum range will result in the best quality water.

COAGULANTS

To reduce the forces keeping the suspended particles apart, chemicals called coagulants are added to the water.

For 95% of the water treatment plants in Ontario, the coagulant used is called alum. The other 5% of water-works use iron salts such as ferric sulphate or ferric chloride.

$Fe_2(SO_4)_3$ - Ferric Sulphate

$FeCl_3$ - Ferric Chloride

Polymers, currently being researched for use as coagulants are discussed in more detail later.

Alum

It may be purchased in the anhydrous form or in the liquid form. The liquid alum is 48.5% solution by weight. This means that in one gallon of liquid alum which weighs 13.5 lbs., there is about 6.5 lbs. of dry alum. (See Topic 7, Water Treatment Chemicals, for more details.) When placed in solution a series of reactions, called hydrolysis, take place.

A simplified version of the reactions that take place is:

1. $Al_2(SO_4)_3.14H_2O = 2Al^{+3} + 3SO_4^{-2} + 14H_2O$

   Alum — Aluminium Ion — Sulphate Ion — Water

2. $H_2O = H^+ + OH^-$

   Hydrogen Ion — Hydroxyl Ion

3. $2Al^{+3} + 6OH^- + 2Al(OH)_3 + H^+$

   Aluminium Ion — Hydroxyl Ion — Aluminium Hydroxide

Reaction (3) illustrates the hydroxyl ions from reaction (2) combining with the aluminium ions from reaction (1), resulting in a surplus of hydrogen ions (H^+) in solution. As outlined earlier in the course, the pH is the measurement of the hydrogen ions in solution. As the hydrogen ion concentration increases, the water becomes more acidic; and the pH of the water is decreased. With an increase in the amount of alum being added to the water, more hydroxyl ion will be used up and more hydrogen ion will become free; thus reducing the pH even further. This reduction in pH may play an important role in the corrosiveness of treated water.

Ferric Coagulants

Ferric coagulants are used over a wide pH range of 4.0 to 11.0. With many colour removal operations taking place at a low pH, the ferric coagulants are very useful. At high pH values (where aluminium hydroxides are soluble) the ferric hydroxides are insoluble. This makes the use of ferric coagulants in iron removal and softening particularly attractive.

1. Ferric Chloride

   Ferric chloride is available in liquid, crystal and anhydrous forms. It is very corrosive and must be handled carefully. The reactions of ferric chloride in water are similar to those of alum.

   a) $FeCl_3.6H_2O = Fe^{+3} + 3Cl^- + 6H_2O$

   Solid Ferric Chloride — Ferric Ion — Chloride Ion — Water

   b) $H_2O = H^+ + OH^-$

   c) $Fe^{+3} + 3OH + Fe(OH)_3$

   Ferric Hydroxide

With the liberation of hydrogen ions, H^+, the water becomes more acidic. The chloride ions in this low pH environment are very corrosive to most types of steel alloys, even stainless steel. The natural alkalinity is reduced by 0.9 mg/l with the addition of only 1.0 mg/l ferric chloride.

2. Ferric Sulphate

Ferric sulphate, $Fe_2(SO_4)_3$, is available as an anhydrous material that is readily soluble in water. Solutions are made by stirring one part by volume of ferric sulphate with two parts of water to produce a solution of about 40% ferric sulphate. This concentrated solution is then diluted to the desired concentration. Ferric sulphate, like alum, reacts with the natural alkalinity of the water.

Alkalinity Reactions

Other chemical reactions that take place during coagulation are those involving the water's natural alkalinity. This alkalinity is made up of calcium bicarbonate $Ca(HCO_3)_2$, sodium bicarbonate $NaHCO_3$, and sodium carbonate Na_2CO_3.

These natural alkalinity constituents react with the sulphate ion (SO_4^{-2}) which is released by alum and shown on P.3-7. equation (1). As a result of this series of reactions the formation of sodium sulphate (Na_2SO_4) and calcium sulphate ($CaSO_4$) occurs. In addition, carbon dioxide (CO_2) is also produced. This carbon dioxide can lead to bubbles within the floc particles and the problem of floc "floaters" can result. In addition, the natural alkalinity of water will be reduced. This reduction is significant to plants that require high alum dosages with little raw water alkalinity as corrosion problems and high residual aluminium problems may occur. *(A rule of thumb is that 1 mg/l of alum will reduce the natural alkalinity of water by 0.45 mg/l.)*

FLOCCULATION

In the Basic Water Treatment Operation Course, the flocculation process was described as the growth of the floc through constant collisions of the neutralized alum/turbidity complexes formed in the coagulation process. With the aid of the mechanical mixers supplying the floc with a slow gentle mix and sufficient time for the floc to grow, we obtained a floc that would settle properly and be tough enough to withstand the forces exerted on it within the filter bed.

COLD WEATHER OPERATION

With the coming of winter the water temperature drops to below $40^{\circ}F$. Many water treatment plants operating near capacity begin to experience a variety of problems. The cold water slows down the rate of the coagulation reaction and particularly the flocculation stage. The result is usually a small floc that does not settle readily. This results in a floc carryover from the sedimentation system on to the filters. The filters could behave in the following ways:

1. The filter runs may be shortened due to the increase in solid loadings.

2. The filter may break through; that is, they may suddenly, at a head loss below their terminal head loss, have an increase in their effluent turbidity. This effluent turbidity may not be much different to the settled water turbidity and the filter will have to be back-washed almost immediately. An example of this is illustrated in Figure 3-4.

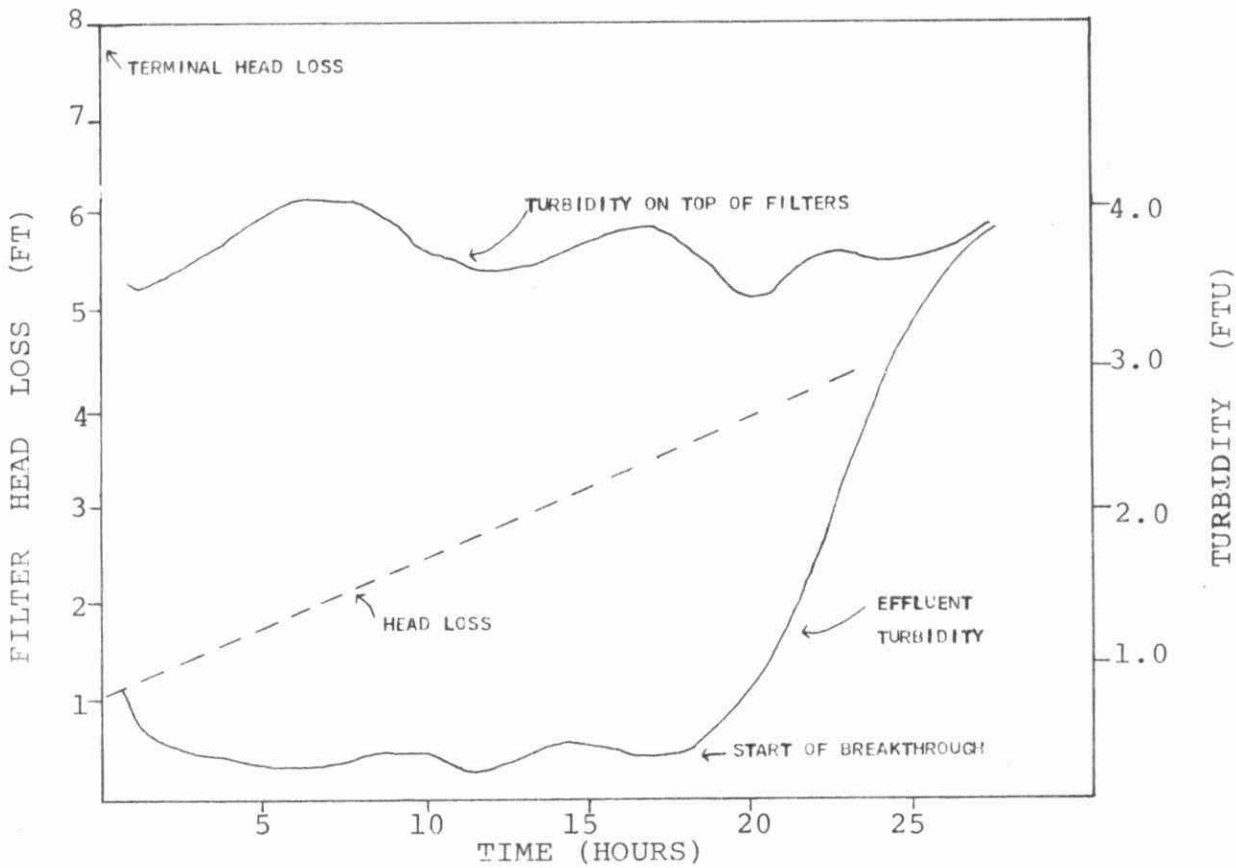


Figure 3-4 Breakthrough Characteristics

Naturally, if the breakthrough is not noticed for a few hours, high turbidity water will flow into the clear well and cause high turbidity problems within the distribution system.

3. The treated water may contain a high residual aluminium content. Residual aluminium is the amount of aluminium that stays in solution and does not react to form the insoluble aluminium hydroxide complex. Just as a teaspoonful of sugar dissolved in tea will not be removed by a filter, the dissolved aluminium will pass through the filter. This may arise due to filter breakthrough described previously or insufficient reaction time. In some cases this is due to a

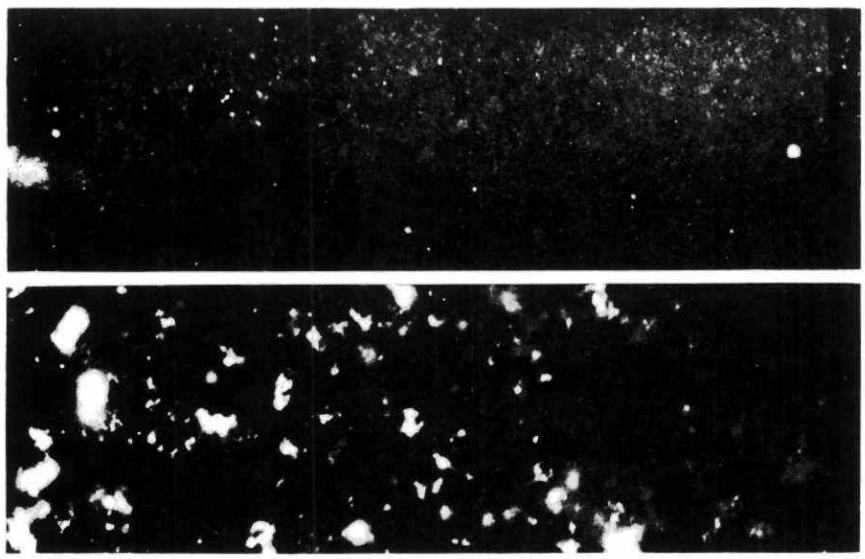
high flocculation pH but in winter very often the aluminium has had little time to react and passes directly through the filter. The result may be a floc formation in the clear well or in the distribution system and complaints of white specks in the water. Other problems of high residual aluminium may be the coating of pipelines or problems in the textile industries.

COAGULATION AIDS FOR COLD WATER

Activated Silica

Both activated silica and polyelectrolytes are very useful in winter. As described in the Basic Water Treatment Operation course, sodium silicate is activated by a number of chemicals including sodium bicarbonate and chlorine. The activated silica when used in conjunction with alum produces a bigger and tougher floc. The physical difference of the two types of floc is illustrated below.

— Top photo shows coagulation with alum alone; bottom photo, compared with alum plus activated silica.



Courtesy: National Silicates Ltd.

The activated silica molecule, a negatively charged, long chained polymer structure, acts as a bridge between floc particles in a manner which is illustrated on page 3-14.

Some of the advantages of Activated Silica are:

- Improved quality of filtered water.
- Broader pH range of treatment.
- Good flocculation of widely varied water, including spring runoff on heavy rains.
- Increased compaction of sludge.
- Longer filter runs, use of higher filter rates.
- Reduced chemical cost.
- Increase of plant capacity.
- Helps to reduce the residual aluminium content of the filtered water, thus preventing "after floc" problems.

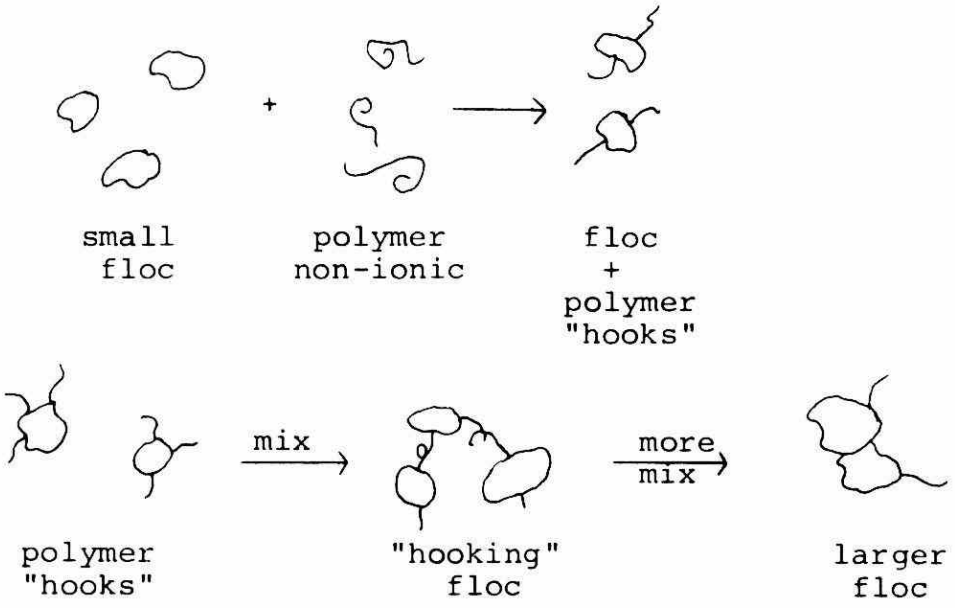
Polyelectrolytes

Polyelectrolytes (polymers) consist of long chains of carbon atoms. Like activated silica, polymers help to produce a superior floc in difficult situations. The three classes of polymers are:

1. Non-ionic - no charge
2. Anionic - negatively charged
3. Cationic - positively charged

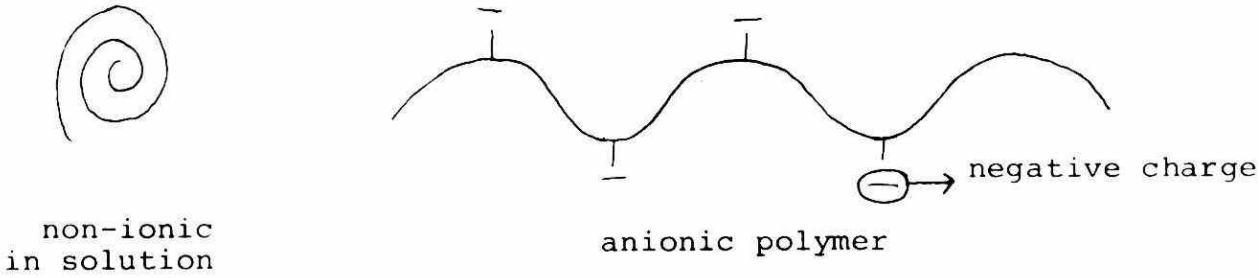
1. Non-ionic

   Our experience has been that if the operation is experiencing slow growth floc or small floc that will not settle properly, the floc growth may be aided by a non-ionic floc. A suggested mechanism is illustrated on page 3-14.



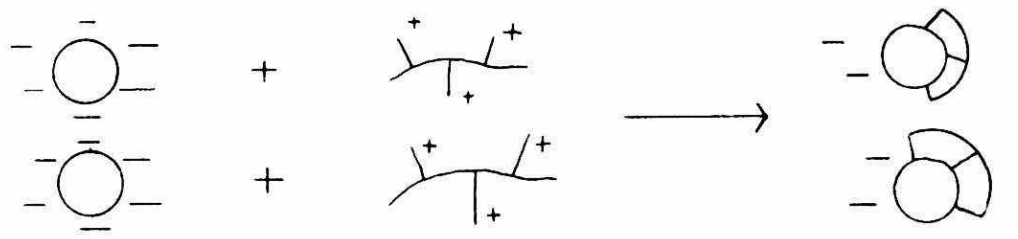
The "hooking" or "bridging" action of the polymer results in larger floc particles being formed. This larger floc is tougher and heavier and able to overcome all or most problems associated with cold weather.

2. Anionic polymers work in a manner similar to activated silica. They are usually used in situations when charge neutralization is not an important factor in suspended solids removal. The advantage of anionic polymers over non-ionic is the available chain length when they are placed in solution. Where the non-ionic polymers curl when placed in solution, the anionic polymers stretch out due to the repulsion of the negative charges on its branches, as illustrated below.



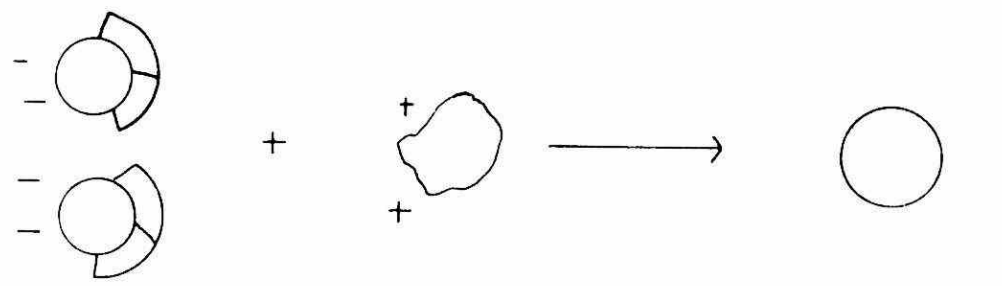
As discussed earlier, the "bridging" or "hooking" mechanism of these polymers aids in the flocculation process.

3. Cationic polymers are used in instances where the volume of the floc is causing problems such as carryover and short filter runs or sludge disposal problems. The cationic polymers substitute their positively charged structure for the alum complex which is a much larger structure.



colloid particle | cationic polymer | partially destabilized particle

The partially destabilized particles then react with the alum complex to obtain charge neutralization and a start to floc formation.



partially destabilized particle | alum complex | floc particle

The floc particle formed is smaller than the alum floc alone. This results in longer filter runs and reduced clarifier blanket levels. Tests have indicated that alum demand can be reduced by 40% or more. Polymers added to strengthen the floc just before the filter to prevent filter breakthrough are discussed in the "Filtration Topic".

The advantages of the polymers include:

- Improved quality of the filtered water.
- Lower sludge volumes.
- Longer filter runs; use of higher filter rates.
- Reduced chemical costs.
- Increased plant capacity.

ALGAE PROBLEMS

Algae occurrence in raw water and in the treated water can have far-reaching effects on the operation of the water treatment plant. These problems may be listed as:

- Taste and Odour
- Filter Clogging
- Coagulation Interference
- Reservoir Coatings

Taste and Odour

As outlined in Basic Water Treatment Operation, the variation in tastes and odours caused by algae has a wide range. The odours may be classified as follows:

1. Aromatic Odour - These odours are very often described as a particular flower or vegetable. Organisms in small numbers can produce these odours.

   Examples as illustrated on Page 3-18 are:

   a) Dinobryon --- Violet

   b) Tabellaria --- Geranium

2. Fishy Odour - These odours are often produced by the same algae that produce the aromatic odours. The organisms are usually present in much larger numbers.

3. Grassy Odour - This odour is very common when the green algae are present in large numbers.

   Examples on Page 3-18 are:

   a) Pediastrum

   b) Scenedesmus

   c) Spirogyra

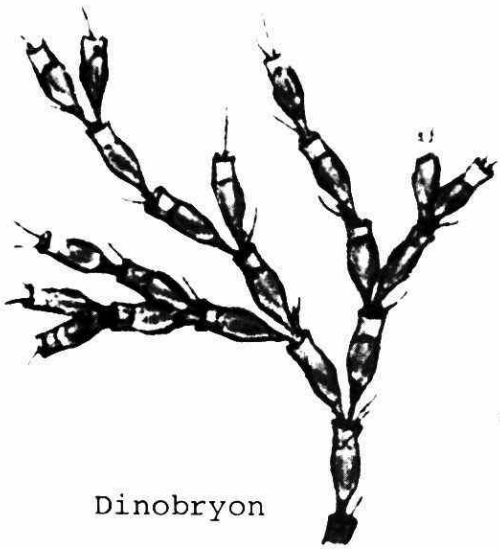
4. Musty and Earthy Odour - The musty odour in some waters is very often encountered in the presence of certain blue-green algae such as Oscillatoria and Melosira, shown on Page 3-19. Earthy odours are commonly associated with actinomycetes.

The control and prevention of many of these tastes and odours may be with the use of:

- Chlorine
- Carbon
- Potassium Permanganate (See Taste and Odours topic of this course)
- Microstraining, another preventive measure, will be described later in this topic.

Figure 3-5 TASTE AND ODOUR ALGAE

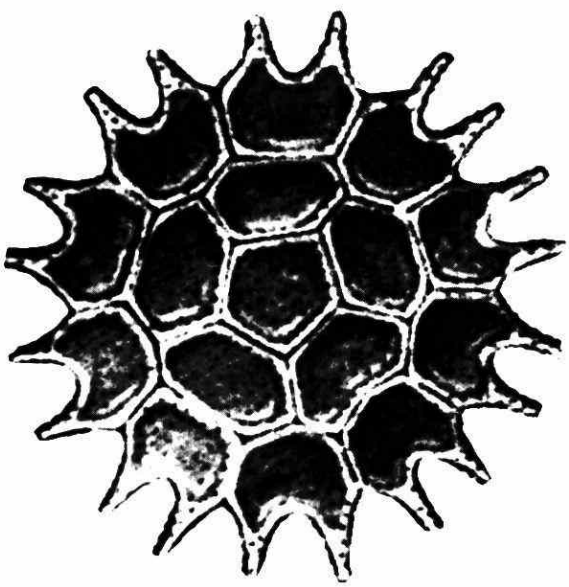
Aromatic Odour



Dinobryon

Tabellaria

Grassy Odour



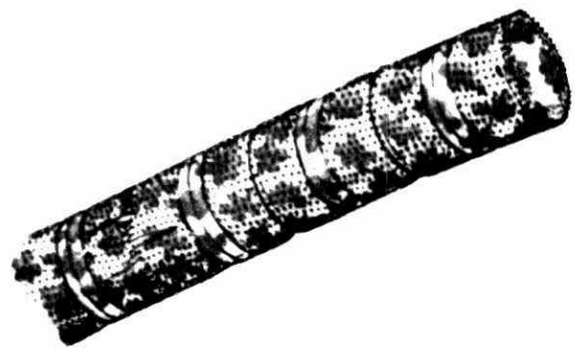
Pediastrum

Scenedesmus

Spirogyra

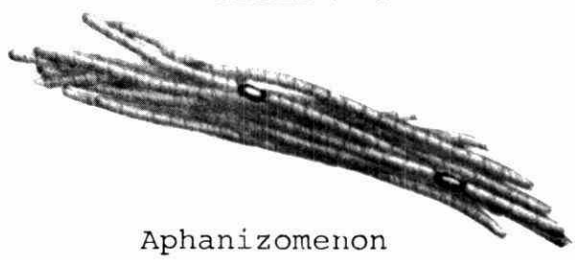
Figure 3-6 Musty and Earthy Odour

Oscillatoria



Melosira

Stringy Floc



Aphanizomenon

Filter Clogging

As water passes through a sand or a coal-sand filter in the treatment plant, the spaces between the filter grains become filled with floc and other suspended matter. Very often, the algae are well represented in the suspended matter. If improperly treated by coagulation and sedimentation facilities, they will very often become the primary reason for filter blockage.

Efficient coagulation and sedimentation may remove up to 90-95% of the raw water algae. The 5-10% of the algae being carried over into the filter bed may still reduce the filter runs.

On the Great Lakes, *diatoms* are well known for their filter clogging ability. Their rigid cell walls do not disintegrate after being killed by chlorine. They form a mat on the filter surface and reduce filter runs (in extreme cases) up to 90%. Water plants that do not use sedimentation facilities, such as direct filtration plants, are very susceptible to filter clogging problems. Diatoms usually are present in troublesome numbers in the early spring and fall with the water temperature near $12^{o}C$.

Coagulation Interference

In the operation of many of Ontario's water treatment plants, the raw water may go through a period of low turbidity. Since this low turbidity leads to greater light penetration of the water, algae very often flourish in abundance. This presents a problem of *"low turbidity - high algae"*. Because there is very little turbidity to weight the floc, higher carryover of algae from the sedimentation tank occurs. This may result in shortened filter runs, also, clarifier operations may experience a deterioration of the floc blanket and subsequent carryover. To aid in the formation of a heavy floc that will weight the floc and lead to algae entrapment and proper settlement, we have "weighting agents". These include clay, bentonite, fuller's earth and other similar materials composed of finely divided insoluble particles.

Other problems include a "stringy" algal floc that is very difficult to flocculate properly. Examples of this are Oscillatoria and Aphanizamenan, shown on Page 3-19. They are often carried over onto the filter bed and coat the filter media granules. This may necessitate longer surface washes than normal to free the filter media from the algae.

In most instances, both taste and odour as well as short filter runs result when the water plant is subjected to algae levels higher than those normally encountered. These high algae levels are usually reached when the algae has both an abundance of food and the correct climatic conditions; the duration of high algae levels may be a few hours to several weeks in the case of diatoms. Blue-green and green algae "blooms" may occur periodically for several days throughout the warmer months. In extreme cases, the pH of the water may rise dramatically from a good coagulation pH of 7.0-7.5 to as high as 8.5. This may lead to a large increase in alum dosage requirements to lower the pH into a proper coagulating pH range.

Breakthrough of a filter with heavy algae loadings on it may release organic matter into the distribution system. This could lead to problems of hydrogen sulphide gas and red water conditions (in extreme cases) accompanying the consumption of the chlorine residual.

Problems such as the production of "floaters" within the floc blanket of a clarifier may be due to gas production within the algae organism when it is killed. Obviously, this gas will lighten the floc and lead to floc carryover and excess algae loading onto the filters.

The decomposition of organic matter, such as dead algae, in sedimentation systems may lead to taste and odour levels in the treated water higher than those in the incoming raw water.

Reservoir Coatings

Algae difficulties in reservoirs and lakes serving as reservoirs include growth of long filamentous algae (Cladophra). When this material breaks free, it may result in the development of septic odours if allowed to rot.

Discoloration of reservoir surfaces is another problem caused by algae. For example, Achnanthes can cause a brown layer of growth.

Prevention of algae growths can be controlled to a large extend by keeping a good chlorine residual in the reservoir and preventing light penetration.

Removal of growths, in most instances, should be restricted to physical means. The use of chemicals to kill attached algae may lead to the release of slimes into the water causing taste and odours. If problems are severe and chemicals must be used, the Biology Water Technology Section of the Ontario Ministry of the Environment should be contacted for assistance.

ALGAE PROBLEM PREVENTION

The operator, relying heavily on past experience, should be able to react quickly to algae problems and be well versed in the preventive measures.

Taste and Odour

The prevention or minimization of taste and odour problems due to algae will be discussed in some detail later in this course.

Filter Clogging Algae

If properly maintained coagulation and sedimentation facilities are unable to prevent plugged filters due to algae, it may be necessary to incorporate the use of a microstrainer. If the algae levels are sufficiently high for much of the yearly plant operation, microstraining can:

1. Reduce the load on the plant.
2. Reduce filter wash requirements.
3. Maintain plant capacity under overload conditions.
4. Increase output to meet higher demands.
5. Reduce chemical use and resulting sludges.
6. Be economically operated.

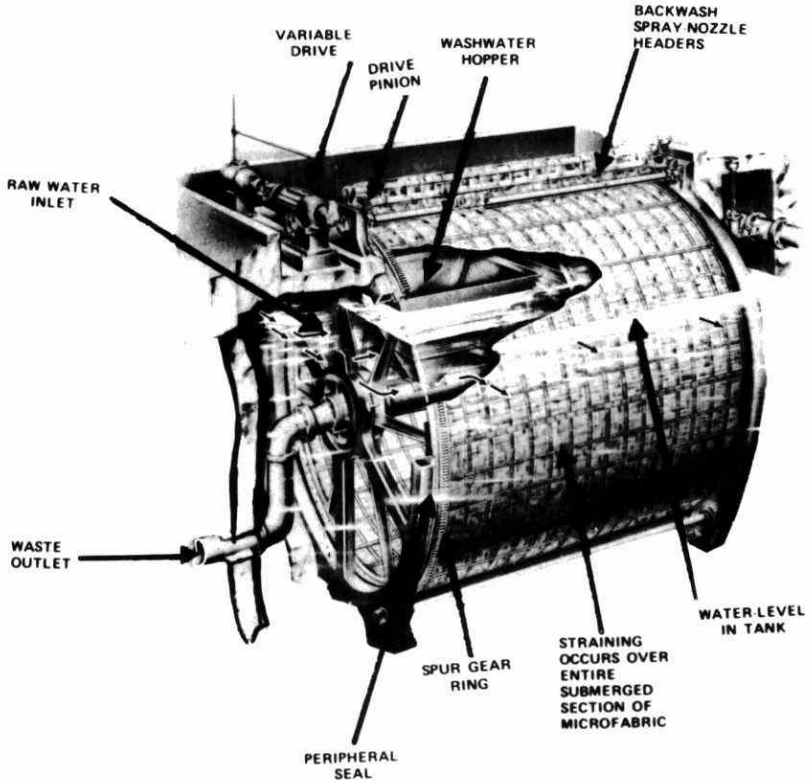
Very often microstrainers are used as the only filtration of water if the colour, colloidal turbidity and living organism levels are low. The microstrainer drum, illustrated in Figure 3-7, can be used to remove algae prior to coagulation, sedimentation and filtration. Usually they are installed ahead of the sand or dual filters.

Other methods of reducing filter clogging carryover onto the filters include the use of a ferric coagulant with lime. Under the proper pH conditions, the ferric coagulant with lime used instead of alum with lime produces a denser floc blanket. The iron floc is heavier and allows fewer algae particles to penetrate up through its depth. The other advantages of iron coagulants will be outlined in more detail in the Coagulation B Section.

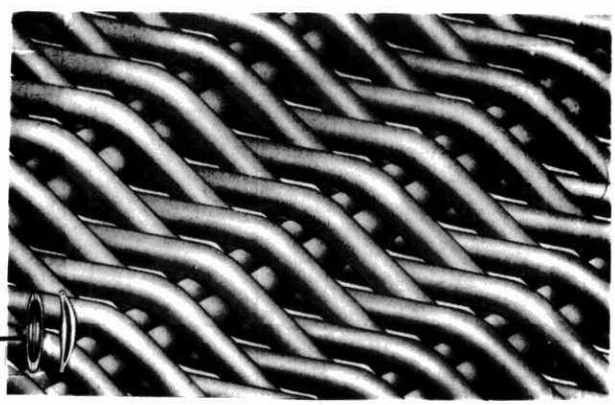
Reservoirs

The prevention of growth in reservoirs can best be accomplished through the reduction of light into the system. Combined with a chlorine residual, the algae growth rate should be severely reduced.

The removal of algae growths is best accomplished by mechanical means. Dead algae growths should be removed immediately to prevent taste and odour problems.



Microstraining Filter



Typical diatom (Cymbella) shown against fabric

Magnified View of Filter Fabric

Figure 3-7 MICROSTRAINER

Courtesy
CRANE-GLENFIELD

Coagulation Interference Preventative Review

1. Light Floc - Use of weighting agents.

2. Stringy Floc - change in coagulant and use of weighting agents.

3. pH Change - use of pH correcting chemicals such as acid or lime.

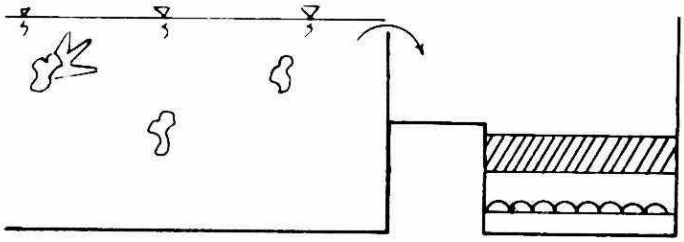
4. Breakthrough - proper monitoring of filter effluent.

5. Floating Floc - use of skimmers on clarifiers or in sedimentation systems.

6. Taste or Odour - frequent sludge blow off or physical removal.

These are illustrated on Page 3-26.

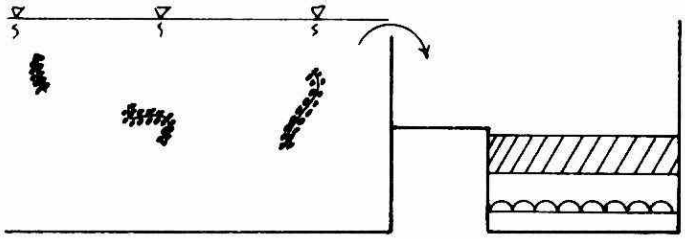
COAGULATION INTERFERENCES - PREVENTATIVE REVIEW



LIGHT FLOC
CARRY OVER

Due to low turbidity

use of weighting agents

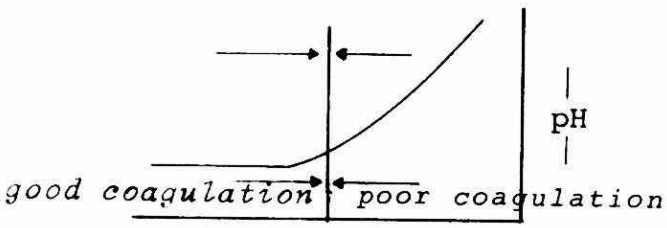


STRINGY FLOC
CARRY OVER

Coats filter media

change in coagulant

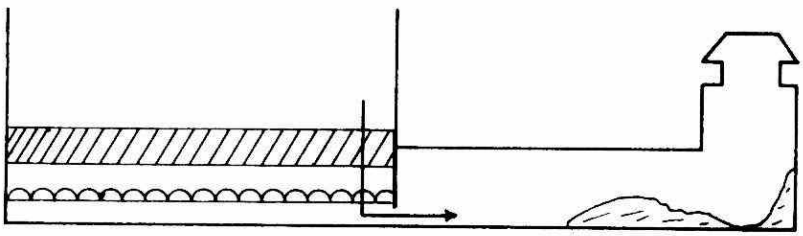
use of weighting agents



INCREASE OF pH

Into poor coagulation zone.

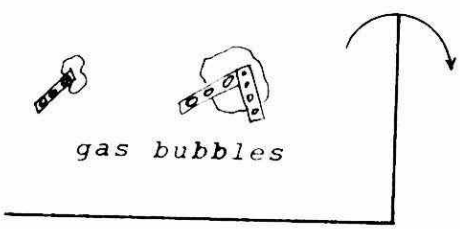
use of pH correcting chemicals such as acid or lime



BREAKTHROUGH OF
ORGANIC MATTER

- Red water
- Hydrogen Sulphide
- No chlorine res.

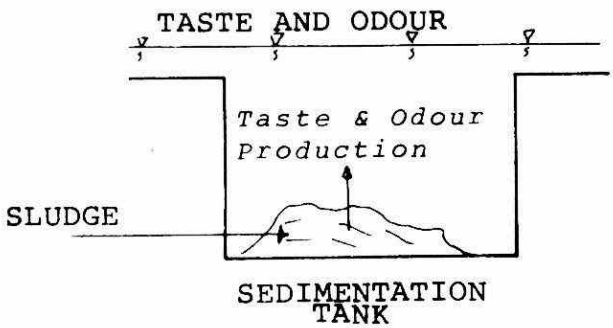
proper monitoring of filter effluent



PRODUCTION OF FLOATING
FLOC CARRY OVER

due to gas

use of skimmers on clarifiers or in sedimentation systems



TASTE AND ODOUR

- *frequent sludge blow off or physical removal*

SUBJECT:

SURFACE WATER TREATMENT OPERATION

TOPIC: 4
Coagulation
- Colour Removal
- Coagulation pH
- Mixing

OBJECTIVES:

The trainee will be able to:

1. Understand the following properties of colour in water:
   a) characteristics
   b) importance of low alkalinity in coloured water
   c) colour removal dependence on pH
   d) the effect of prechlorination
2. Recall the importance of pH on:
   a) the removal of colour
   b) the distribution system
   c) the effectiveness of the chlorine dose.
3. Understand the meaning of the following terms in mixing:
   a) velocity gradient
   b) nominal retention time
   c) short circuiting
   d) flash mixing, flocculation and blending.
4. Correct problems by:
   a) determining the proper alum dosage and feed rate
   b) using coagulant aids
   c) optimizing the pH for colour removal
   d) low alkalinity waters.

COAGULATION

COLOUR REMOVAL

In the Basic Water Treatment Operation Course, the occurrence of organic colour in water was attributed to complex organic compounds formed when the water leaches the colour out of disintegrating woody and vegetable materials in the water.

Properties

Colour is made up of a number of organic compounds which are usually categorized as "humic substances". The general properties of "humic substances" are:

1. Size in the range of 0.003 to 0.02 microns. One can appreciate how small this is as the colloidal turbidity particles are in the range of 0.05 to 0.15 microns. (25,400 microns = 1 inch)
2. The colour particles are negatively charged due to the chemical groups attached to the humic substances.
3. The magnitude of their chemical charge is dependent on the pH of the water.

Types and Levels

When determining the colour content of water, a difference between straight raw water colour and a filtered water colour may be noticed. The difference is due to the non-coloured suspended matter that interferes with the colour equipment. The colour of the raw water is known as the *apparent* colour. The colour of the water having been centrifuged and decanted is known as the true colour.

Colour levels commonly encountered in Ontario vary from:

0-5	Hazen	Great Lakes
30-60	Hazen	Ottawa River & Southern Ontario Rivers
100-150	Hazen	Northern Ontario Lakes & Rivers

Of course, there are exceptions to this guide but generally speaking most highly coloured waters are found in Northern Ontario.

PROBLEMS FROM COLOUR REMOVAL TREATMENT

Colour removal is usually more difficult than turbidity removal for a number of reasons. These include:

1. Colour removal requires higher alum dosages than those required for turbidity removal.
2. Highly coloured waters are often low in alkalinity.
3. Colour removal is dependent on the coagulation pH.
4. Coloured water often lacks sufficient turbidity levels to produce a "heavy" floc.

High Alum Dosages

High alum dosages to remove colour are generally undesirable both from an economical point of view as well as from a treatment standpoint. The alum dosages (which reach 100 mg/l occasionally) add significantly to the cost of plant operation. In addition, the treatment requirements for the new water plants now require that the backwash and sedimentation tank sludge be restricted for discharge back into the river or lakes. With alum dosages approaching 100 mg/l, the sludge volume is very large and its treatment adds a significant increase to the cost of the plant. Simple mathematics shows that a 2 MGD treatment plant in Northern Ontario could produce as much sludge as a 20 MGD plant in Southern Ontario which requires only 1/10 of the alum for treatment. The sludge treatment costs, for the smaller system, would be the same as those for the larger plant but the percentage of the total treatment costs would be much higher.

The high alum dosages will also depress the treated water pH even lower as well as reduce the alkalinity levels to undesirable levels. Both the pH and alkalinity would have to be corrected prior to leaving the plant.

Low Alkalinity Levels

As mentioned earlier, 1 mg/l of alum will reduce the alkalinity levels of the raw water by approximately 0.45 mg/l. With many highly coloured waters the raw water alkalinity levels are 20-50 mg/l. (If the raw water alkalinity was 30 mg/l and the alum addition was 60 mg/l the treated water alkalinity would be reduced by 27 to a level of 3 mg/l). The indications are that when the alkalinity level of the treated water drops to less than 10 mg/l, problems arise with high residual aluminum levels and possible after-floc formation. This problem can be overcome by the addition of artificial alkalinity such as sodium bicarbonate to raise the treated water alkalinity level to greater than 10 mg/l. Sodium bicarbonate is added before the alum and has little effect on the pH of the water. Sodium carbonate is seldom used for increasing the alkalinity since it increases the pH quite significantly.

Colour Removal Dependence on pH

As outlined earlier, each colour particle is characterized by the chemical groups attached. As the pH of the water is changed the number and type of chemical groups attached to the colour particle also changes. This change directly affects the negative charge of the particle. As a result, the alum requirements for neutralization will vary depending on the pH. Figure 4-1 depicts pictorially the use of acid with alum. Figure 4-2 indicates the results that may occur over a range of coagulant levels.

As Figure 4-1 indicates, the alum requirements for colour removal are reduced with the use of acid. The optimum pH range in this case was 6.0 - 6.5. The term optimum pH range means that pH range where the nature of

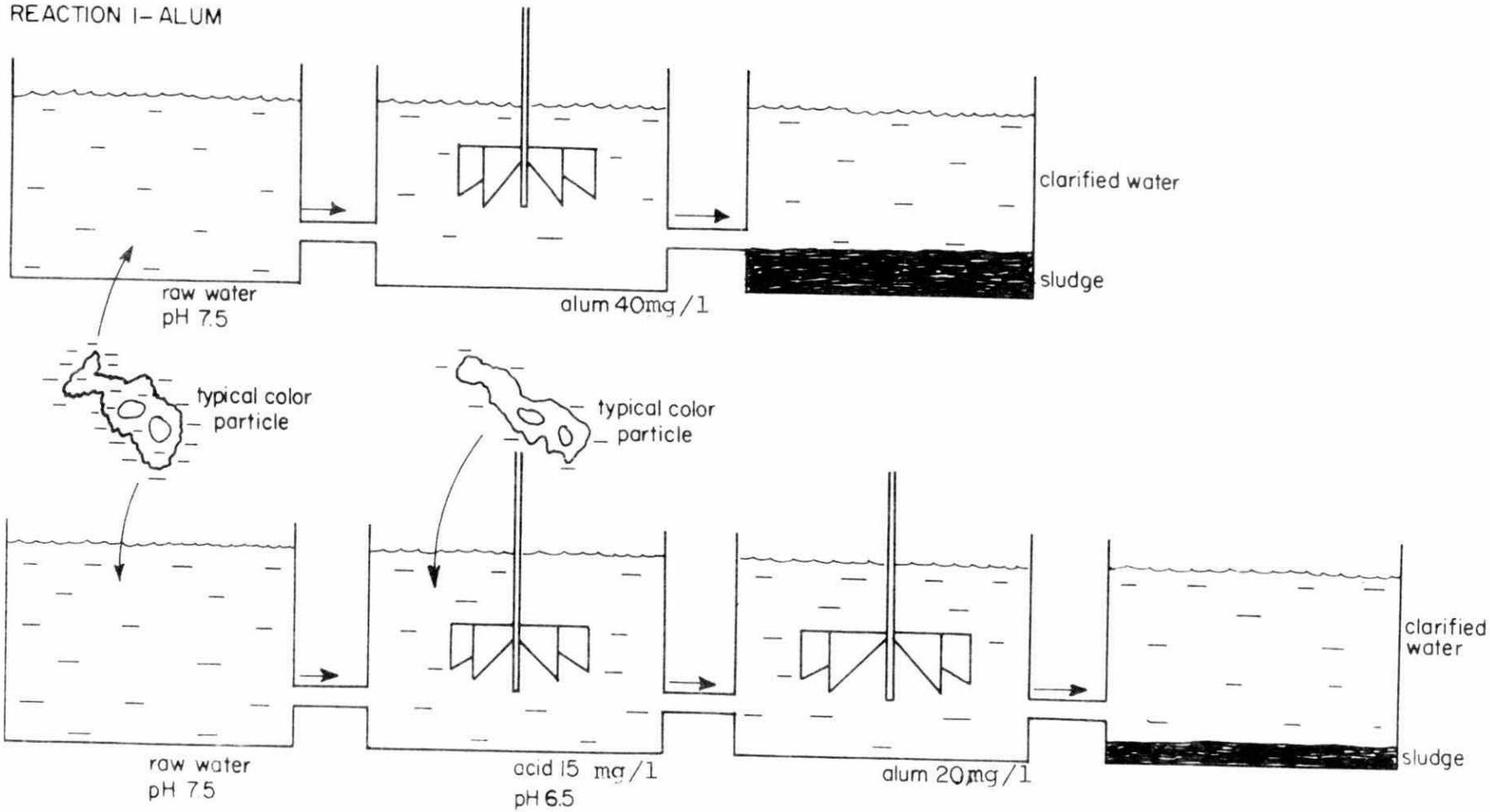
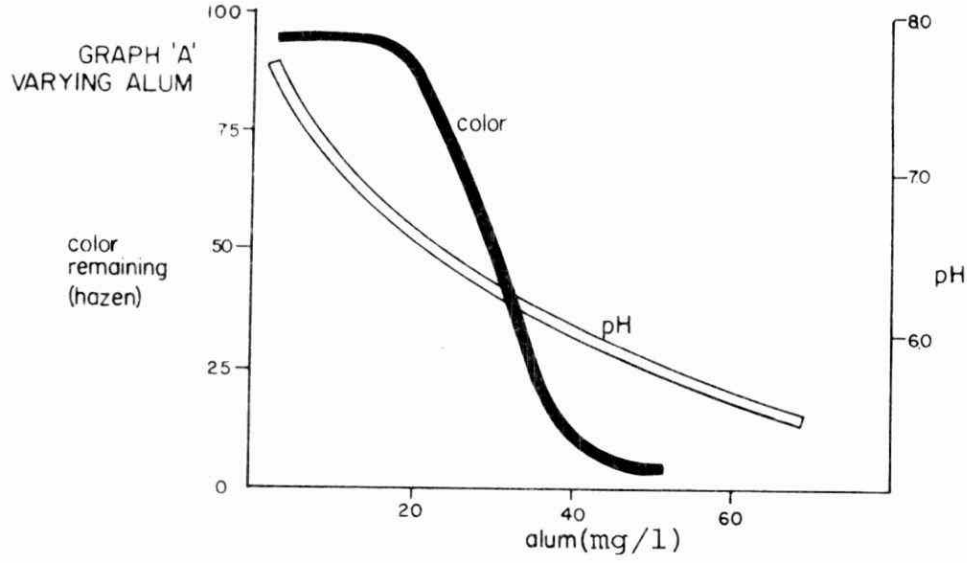
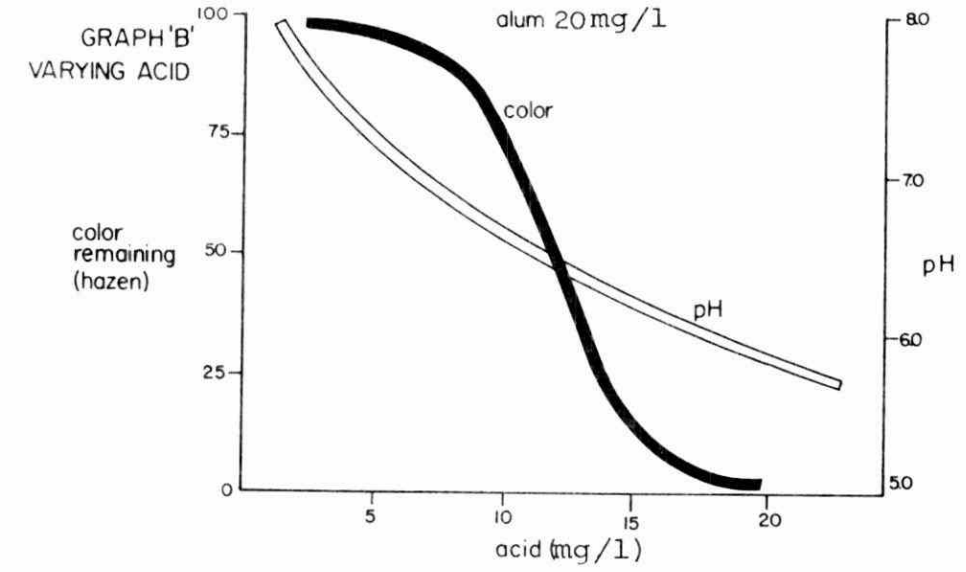


Figure 4-1 USE OF ACID IN COLOUR REMOVAL





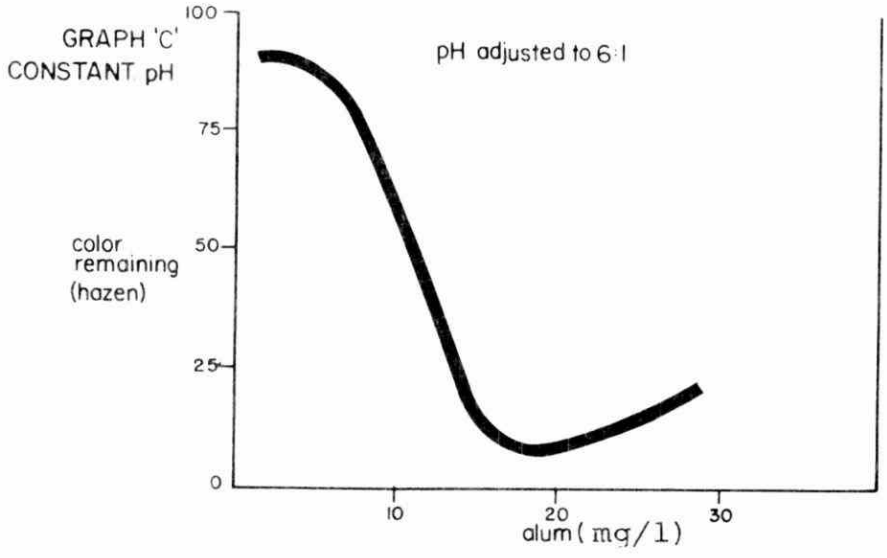


Figure 4-2 COLOUR REMOVAL GRAPHS

the colour particles is sufficiently altered to permit their removal with the least amount of coagulant.

In Reaction 1, 40 mg/l of alum were required to reduce the pH to the 6.0 - 6.5 range and successfully remove the colour. On the second reaction 15 mg/l of acid lowered the pH of the raw water to a level where 20 mg/l of alum was sufficient to remove the colour through coagulation or precipitation mechanism.

A review of the graphs in Figure 4-2 indicates that:

1. As the alum is increased, the pH decreases and the colour is successfully removed with 40 mg/l of alum at a pH of about 6.1.
2. With the alum dosage constant at 20 mg/l, the colour is successfully removed at a pH of 6.1 (15 mg/l acid aided in depressing the pH to this level).
3. At a pH of 6.1 (adjusted with acid) the successful removal of the colour particles takes place with 20 mg/l of alum. This is a finding that confirms that of Graph B.

Light Floc

As discussed both in the Basic Water Course and in the Cold Water Problem Section, the problem of light floc often results in carry-over problems, shortened filter runs and possible filter breakthrough. The corrective possibilities include the use of coagulant aids on possible sludge recirculation. With the high alum dosages required for colour removal, the correct use of both coagulant and coagulant aid is very important.

Some research work has been done in colour removal water plants. The findings from the Ottawa River include the following:

1. Alum dosage increases as the alkalinity increases.
2. Alum dosage decreases with an increase in the raw water acidity.
3. The pH of the raw water gives no indication of the required alum dosage.
4. Between colour levels of 40 and 80 Hazen there is no relationship between the required alum dosage and the colour concentration.
5. Colour floc is weak and fragile.

The conclusions from the Ottawa River study emphasize the importance of experience and records when operating a colour removal plant. Many questions remain unanswered and much work needs to be done.

Work is presently being carried out throughout the province to reduce the alum requirements for colour removal. Some methods being tested include:

1. The use of polyelectrolytes, as primary coagulants, or combined with a reduced amount of alum.
2. Ozonation and Microstraining;
3. Ozonation and Activated Carbon Filtration.
4. Biological Filtration.

PRECHLORINATION OF COLOURED WATER

Prechlorination serves several valuable roles in the treatment of coloured waters:

1. Controlling odours commonly associated with coloured waters (swampy, musty).
2. Preventing putrefaction of sludge in settling tanks.
3. Controlling bacterial and algae growth within the plant.
4. Oxidizing and precipitating soluble iron salts which are commonly found in coloured waters.

It is usually advantageous to prechlorinate at a dosage sufficient to maintain a free chlorine residual at a filter effluent.

JAR TEST PROCEDURES

The procedure for determining the optimum dosage of both coagulant and coagulant aid is outlined in Topic 13. For optimizing pH with acid, it is best to determine the optimum alum (plus coagulant aid) dosages. Then repeat the jar test adding enough acid to obtain a raw water pH 0.4 to 0.7 units lower than the raw water pH and add alum to each jar successively reducing the alum loadings by 10% for each jar. An example of this technique is outlined on Pages 4-18 and 4-19. When using sulphuric acid it should be noted that *1 mg/l of sulphuric acid reduces the alkalinity by 0.95 mg/l.*

WATER TREATMENT pH PROBLEMS

The pH is the measurement of the acidity or alkalinity of the water. The constituent that is measured by the pH meter is the hydrogen ion (H+) concentration in the water. When the hydrogen ions are in abundance, the water is acidic and the pH can lie between 0 and 6.99 units. If the pH lies between 7.01 and 14 the water is considered to be basic and the hydroxyl ions (OH-) are in abundance. A solution with a pH of 7 is considered to be neutral. This does not mean that a water plant should put water into the distribution system with a pH of 7. An operator has to consider several constituents to produce water that will be neither corrosive nor scale forming. For example, the hardness, alkalinity, dissolved solids and the temperature play important roles.

The pH values for most mineral bearing waters in Ontario lie in the range of 6 to 9. For most water treatment plants, the raw water pH remains relatively constant from month to month.

Biological activities such as photosynthesis and respiration (algae growth characteristics) often change the pH due to the ability of these activities to alter the concentration of the dissolved carbon dioxide.

Significance of pH in Treatment Prior to Distribution

The value of pH has already been discussed in some detail when:

1. The pH has to be optimized to remove colour.
2. The pH has to be controlled to keep the residual aluminum below 0.1 mg/l.
3. The third significance of the pH is its effect on the killing power of chlorine. Table 4-1 illustrates this point.

TABLE 4-1

MINIMUM CHLORINE FOR 100% KILL RATE				
pH	Free Chlorine	Required Contact Time	Combined Chlorine	Required Contact Time
6	0.2	10	1.0	60
7	0.2	10	1.5	60
8	0.4	10	1.8	60
9	0.8	10	1.8	60
10	0.8	10	-	-

A review of this table shows that with an increase in the pH of the water the killing power of chlorine is reduced significantly. For those plants that do not provide breakpoint chlorination and carry a free residual chlorine, very high levels of a combined residual are necessary for up to 60 minutes contact time.

MIXING PROBLEMS

On the Basic Water Treatment Operation Course, the importance of proper flash mixing and flocculation in the general operation of the plant was outlined briefly. Two things are of primary importance in the mixing system. These are:

1. *The degree of mixing.*
2. *The duration of mixing.*

The Degree of Mixing

For most water plants in Ontario today, the water is mixed by mechanical mixers. The mixing is accomplished by the dissipation of power in the water. The term *velocity gradient* (G) is the parameter that expresses the horsepower dissipated in the water to a known volume of that water at a given viscosity. The viscosity of the water is a function of the temperature. Without becoming too technical the velocity gradient levels that generally pertain to standard water treatment plants are:

Standard Mechanical Flash Mixing	G =	200 - 400 sec-1
In line Blending	G =	1000 - 3000 sec-1
Standard Mechanical Flocculation	G =	20 - 50 sec-1
Jar Tester - 1000 ml Beaker 100+rpm	G =	120 - 150 sec-1
25 rpm	G =	20 - 30 sec-1

Prior to the introduction and widespread use of mechanical mixers, many plants relied on baffles in the flocculation tank to do the mixing. Unlike today's mechanical mixers that have speed control devices, the baffled mixing chambers are vulnerable to flow change.

Solution to a Degree of Mixing Problems

A plant operator found that his properly baffled chamber gave an excellent large, fast-settling floc when his water demand was 20 MGD. His velocity through his tank was 1 ft/sec and his mixing G was 30 sec-1. At peak demand the flow through the plant rose to 40 MGD. Not being able to

control either his velocity, now 2 ft/sec,or his G, now 65 sec-1, his floc began to break up prior to entering the sedimentation tank. This break up in the floc resulted in floc carryover on to filters and reduced filter runs. At low demand, with the flow reduced to 6 MGD the velocity was reduced to 0.3 ft/sec and the G was down to 10 sec-1. The operator found that sedimentation was taking place in his baffled flocculation tank. He realized that this settled floc would eventually spill over into the sedimentation tank when the flow increased. But he also knew that with no desludging equipment in his flocculation tank, taste and odour problems possibly could occur if the sludge was left for a long period. His problems were solved when mechanical flocculators were installed and his flocculation tank was sized for peak flow conditions.

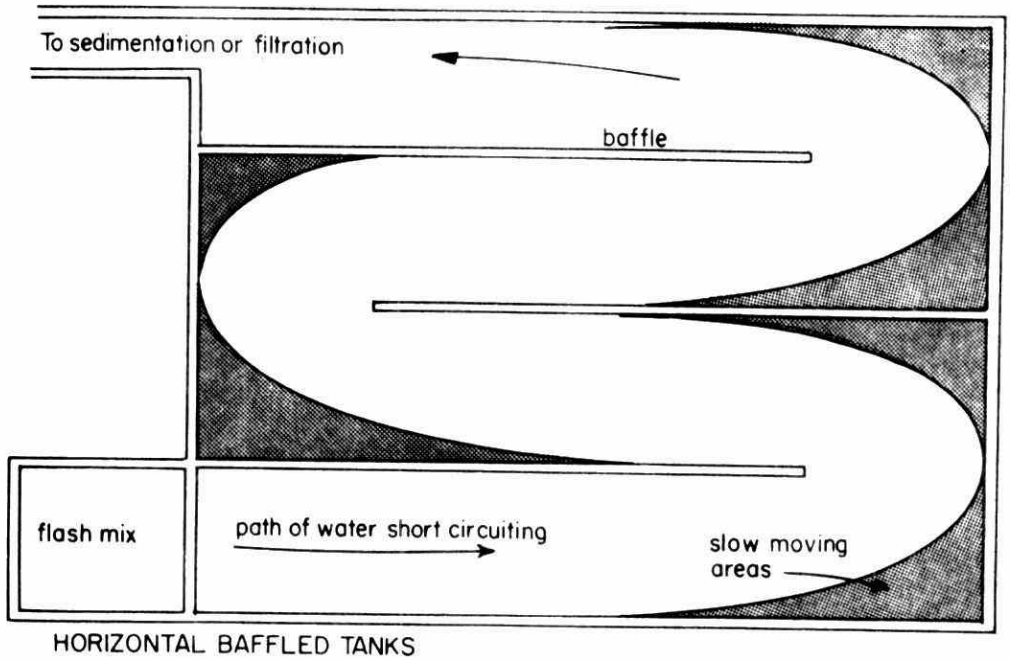
The Duration of Mixing

The duration of mixing is called the retention time. The *Nominal Retention Time* is the length of time a particle theoretically remains in a mixing system. It is determined by dividing the tank volume by the flow through the tank. For example, a 150,000 gal tank with a flow of 200,000 gal/hr through it has a Nominal Retention Time of 0.75 hr or 45 min. In practice, the actual retention time is usually shorter. This is due to the short circuiting of the floc particles in the tank. Figure 4-3 indicates the short circuiting that may take place in a mixing tank.

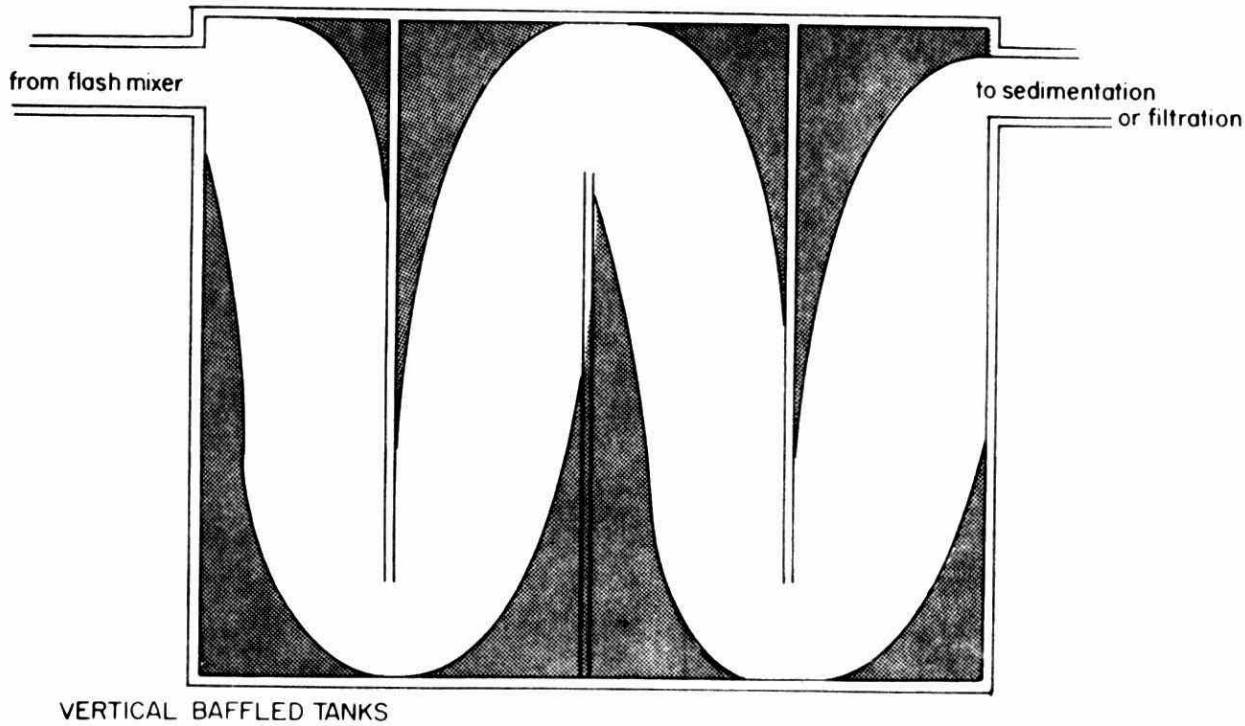
Because of this short circuiting, the actual amount of time that a floc particle is mixed may be much less than the Nominal Mixing Time. Short circuiting in sedimentation tanks is also troublesome, particularly at high flow rates, in many water plants. Often with the correct use of splash plates, baffles and collecting weirs, the short circuiting is kept to a minimum.

Solution to a Mixing Time Problem

An operator who was quite conscientious calculated his Nominal Retention Time for his flocculation system to be 40 min. He did not have any mixing problems until one



HORIZONTAL BAFFLED TANKS



VERTICAL BAFFLED TANKS

Figure 4-3 SHORT CIRCUITING IN MIXING TANK

winter a new industry opened and the operations daily water consumption was increased substantially. He carried out his usual jar tests flocculating his water for 40 min. But he had considerable difficulty in relating his alum dosages in his jars to those alum dosages found to be necessary to prevent floc carryover. Thinking that the problem could be short circuiting in his flocculation basin, he called the Ministry of the Environment District Office. The district staff carried out a retention time test and found the plant water was actually getting less than 20 minutes of flocculation time. The operator repeated his jar tests and found that the amount of alum necessary to produce a good settling floc in his jars after 20 minutes was similar to that of his plant. This amount of alum was considerably more than that needed for 40 minutes of flocculation. Proper baffles were installed in his flocculation basin ensuring a more efficient mix. The plant was then able to produce a good product with less time. Jar test work was now more closely related to the plant requirements.

JAR TEST PROBLEMS

The following set of problems indicate some of the problems that may occur in water treatment plants around the province.

1. Determining the Proper Alum Dosages
2. Coagulant Aids
3. Optimizing the pH for Coloured Water
4. Coloured Water - Alkalinity Problems

Determining Proper Alum Dosages

An operator in a small plant was unable to determine how much alum he should add for various raw water conditions. He contacted his District Engineer and they decided to order jar test equipment. The day his equipment arrived a storm blew in from the West and his raw water turbidity was holding steady at 30-40 JTU. He decided to do his first jar test.

His first set of results are listed on Table 4-2a, Page 4-15. He figures that Jar #3 looked not quite good enough and perhaps Jars #4, 5, and 6 looked too good, so he repeated the jar test using more exact dosages. These are listed on Table 4-2b. From this set of tests he determined that jar #3 was the most economical to do the job and he applied that dosage (33 mg/l alum) to the plant. He also recorded the alum dosage for that plant on his master sheet (Figure 4-4, page 4-16) for future reference.

Coagulant Aids

An operator in Central Ontario has run his plant for several years with few problems. He has developed a curve similar to Figure 4-4, and depending on the raw water conditions he has had few problems until this winter. He has found that with a steadily increasing water demand over the past few years the floc is not settling in his sedimentation tank as it should. He realizes the increase in flow through the tank reduces the sedimentation time in the tank and during this past winter there have been several days of heavy floc carryover on to the filters. The filter runs are generally shorter than previous years and on two occasions he found that the filter broke through the high turbidity water entered his distribution system. After contacting his local District Office he decided on running a trial run with either polyelectrolyte, activated silica or bentonite clay. To decide which would be the most attractive financially and in terms of performance in the plant, he carried out jar tests to determine his optimum dosage. His results are summarized on Tables 4-3a and 4-3b, Page 4-17. (Remember that for the raw water conditions listed his best alum dosage was previously determined to be 25 mg/l).

The activated silica jar test results of this operator are important for a number of reasons. It should be noted that his raw water temperature was 35°F. To keep his lab results consistent with the plant, he carried out his tests with his jars in a constant temperature bath of 35°F water. HIs results indicated that his most economical dosage of coagulants would be 20 mg/l of alum and 3 mg/l of activated silica. On reviewing his results more closely, he noticed

TABLE 4-2 DETERMINING COAGULANT DOSAGE

TREATABILITY
COAGULATION TESTS

TURBIDITY	35	J.T.U.
COLOUR	<5	HAZEN
pH	7.6	
FLOC TEMPERATURE	60°F	
ALKALINITY	80	MG/L
HARDNESS	100	MG/L
IRON	<.05	MG/L
CHLORINE	8	MG/L

DATE June 1973

LOCATION

RAW WATER ANALYSIS
RUN NO. 1

SOURCE Small Lake

	CHEMICALS				pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS						
JAR #	ALUM MG/L	MG/L	MG/L	MG/L	* INITIAL	FLOC	FORM. SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L
1	10				7.6	7.3	poor	poor	poor	2.2	16	7.3	<5	0.5	<.05	75.5	-
2	20				7.6	7.1	fair	small	fair	8	4	7.1	<5	0.2	<.05	71	-
3	30				7.6	6.95	good	good	good	2.1	0.8	7.0	<5	0.09	<.05	66.5	-
4	40				7.6	6.8	good	good	good	1.8	0.35	6.8	<5	0.05	<.05	62	-
5	50				7.6	6.7	good	small	good	1.8	0.35	6.7	<5	0.03	<.05	57.5	-
6	60				7.6	6.6	good	small	fair	2.5	0.6	6.6	<5	0.08	<.05	53	-

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING TIME SPEED G+/1000

2 MINUTES @ 100+ RPM sec^{-1}
25 MINUTES @ 25 RPM sec^{-1}
MINUTES @ RPM
SETTLING TIME 25 MIN

Table 4-2a

TREATABILITY
COAGULATION TESTS

TURBIDITY	35	J.T.U.
COLOUR	<5	HAZEN
pH	7.6	
FLOC TEMPERATURE	60°F	
ALKALINITY	80	MG/L
HARDNESS	100	MG/L
IRON	<.05	MG/L
CHLORINE	8	MG/L

DATE June 1973

LOCATION

RAW WATER ANALYSIS
RUN NO. 2

SOURCE

	CHEMICALS				pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS						
JAR #	ALUM MG/L	MG/L	MG/L	MG/L	* INITIAL	FLOC	FORM. SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L
1	27				7.6	7.05	fair	small	good	3.5	1.00	7.1	<5	0.15	<.05	68	-
2	30				7.6	6.95	good	good	good	2.2	0.76	7.0	<5	0.10	<.05	66.8	-
3	33				7.6	6.9	good	good	good	1.8	0.35	6.9	<5	0.05	<.05	65	-
4	36				7.6	6.85	good	good	good	2.0	0.32	6.8	<5	0.04	<.05	64	-
5	39				7.6	6.8	good	good	good	1.9	0.30	6.8	<5	0.06	<.05	62.5	-
6	42				7.6	6.8	good	good	good	1.7	0.36	6.8	<5	0.05	<.05	61	-

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING TIME SPEED G+/1000

2 MINUTES @ 100+ RPM sec^{-1}
25 MINUTES @ 25 RPM sec^{-1}
MINUTES @ RPM
SETTLING TIME 25 MIN

Table 4-2b

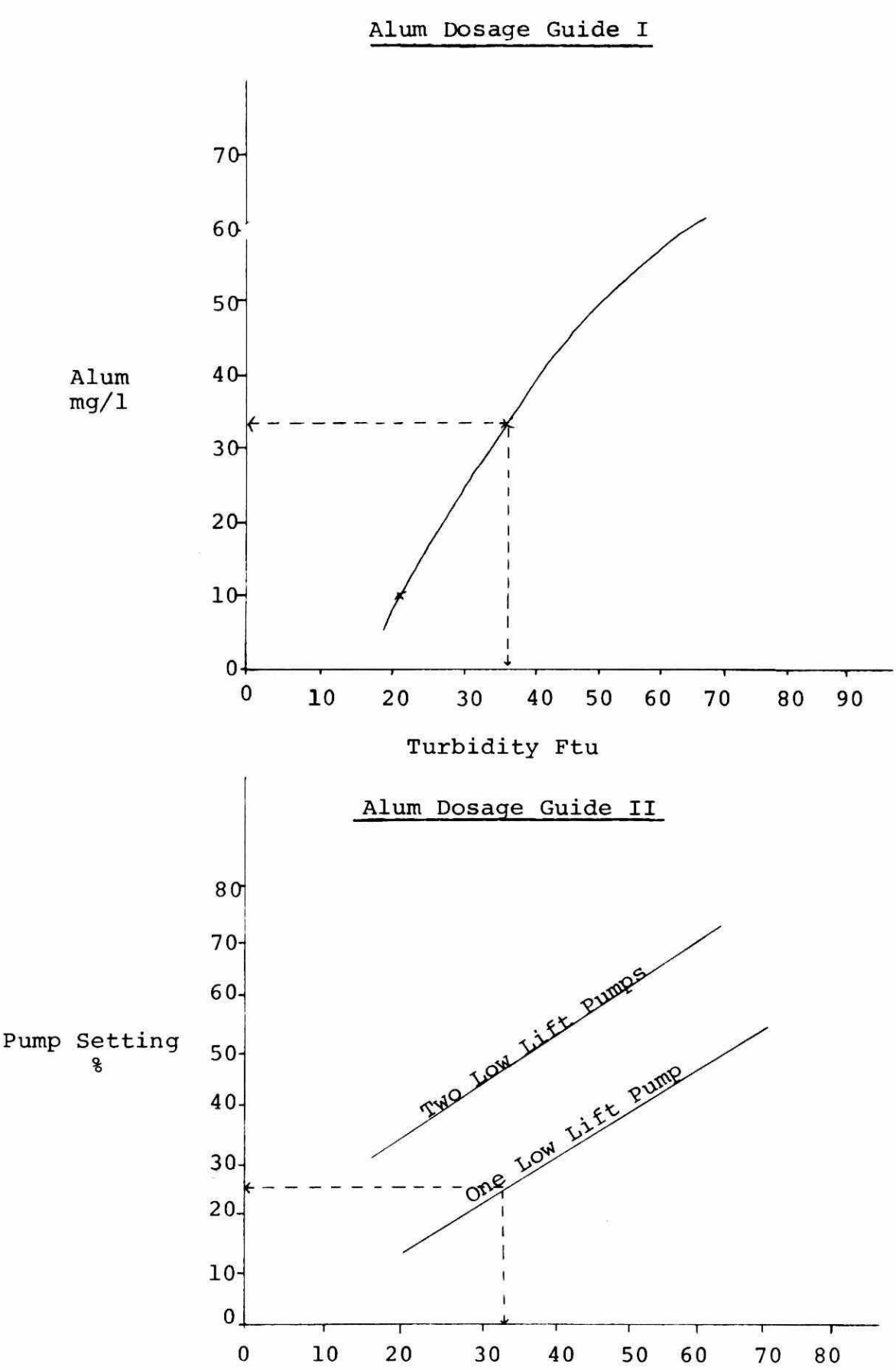


Figure 4-4 ALUM DOSAGE GUIDES

TABLE 4-3 DETERMINING DOSAGE OF COAGULANT AND COAGULANT AID

TREATABILITY
COAGULATION TESTS

TURBIDITY	2.2	J.T.U.
COLOUR	< 5	HAZEN
pH	7.6	
FLOC TEMPERATURE	35°F	
ALKALINITY	60	MG/L
HARDNESS	70	MG/L
IRON	0.1	MG/L
CHLORINE	5	MG/L

DATE Winter 1973

LOCATION Central Ontario

RAW WATER ANALYSIS
RUN NO. Activated Silica Test

SOURCE Lake

	CHEMICALS				pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS							
JAR NO.	ALUM MG/L	ACT SILICA MG/L	MG/L	MG/L	* INITIAL	FLOC	SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L	
1	25	0			7.6	7.1	slow	small	fair	2.4	0.5	7.1	< 5	0.08	<.05	49		
2	25	2.5			7.6	7.2	fair	fair	good	1.0	0.3	7.2	< 5	0.05	<.05	50		
3	25	5			7.6	7.25	fast	big	good	0.9	0.25	7.2	< 5	0.05	<.05	51		
4	22.5	4			7.6	7.3	fast	big	good	0.9	0.3	7.3	< 5	0.05	<.05	52		
5	20	3			7.6	7.3	fast	fair	good	1.1	0.3	7.3	< 5	0.05	<.05	52		
6																		

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING TIME SPEED G+/1000

2 MINUTES @ 100+ RPM sec^{-1}
25 MINUTES @ 25 RPM sec^{-1}
MINUTES @ RPM
SETTLING TIME 25MIN

Table 4-3a

TREATABILITY
COAGULATION TESTS

TURBIDITY	2.2	J.T.U.
COLOUR	< 5	HAZEN
pH	7.6	
FLOC TEMPERATURE	35°F	
ALKALINITY	60	MG/L
HARDNESS	70	MG/L
IRON	0.1	MG/L
CHLORINE	5	MG/L

DATE Winter 1973

LOCATION Central Ontario

RAW WATER ANALYSIS
RUN NO. Polyelectrolite Test

SOURCE Lake

	CHEMICALS				pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS							
JAR NO.	ALUM MG/L	POLY MG/L	MG/L	MG/L	* INITIAL	FLOC	SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L	
1	25	0			7.6	7.1	slow	small	fair	2.4	0.5	7.1	< 5	0.08	<.05	49		
2	25	0.04			7.6	7.1	fair	fair	fair	1.5	0.5	7.1	< 5	0.08	<.05	49		
3	25	0.07			7.6	7.1	good	good	good	0.9	0.3	7.1	< 5	0.08	<.05	49		
4	25	0.10			7.6	7.1	good	good	good	0.9	0.3	7.1	< 5	0.08	<.05	49		
5	20	0.07			7.6	7.1	fair	fair	fair	1.4	0.5	7.1	< 5	0.08	<.05	51		
6	20	0.10			7.6	7.1	good	good	good	1.1	0.4	7.1	< 5	0.08	<.05	51		

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING TIME SPEED G+/1000

2 MINUTES @ 100+ RPM sec^{-1}
25 MINUTES @ 25 RPM sec^{-1}
MINUTES @ RPM
SETTLING TIME 25 MIN

Table 4-3b

that the jar with alum plus activated silica had a slightly higher pH than the jar with alum alone. The same was true for the filtered water alkalinity levels. This is due to the high pH and alkalinity levels of the activated silica solution.

The polyelectrolyte results showed that 25 mg/l of alum and 0.07 mg/l of polyelectrolyte would improve both the settled and filtered water characteristics. The polyelectrolyte dose did not affect either the effluent pH or the alkalinity of the water.

Because the costs were similar for both the activated silica and the polyelectrolyte feed, the operator decided to obtain enough of each to try a one-month study for each in his plant. He contacted his District Office for advice. His District Engineer explained to him that very often equipment for plant scale tests can be obtained for a limited time from coagulant aid salesmen. These technically oriented salesmen also provide expertise based on many years of experience.

Optimize the pH for Coloured Water

The operation was troubled with periodic floc carry-over problems that led to filter clogging problems. In addition, Ministry personnel were becoming more interested in reducing alum levels in colour removal plants. The operator carried out a series of jar tests that are summarized on Table **4-4a.** He decided that Jar #3 with 60 mg/l of alum was the best jar. He noticed that both Jar #1 and Jar #2 had high residual aluminum (greater than 0.1 mg/l) and high colour (greater than 5 Hazen). Although Jars #3,4 and 5 had met all Ministry standards, the operator realized that it is economical to feed the lower alum dosage of 60 mg/l alum. He checked his effluent alkalinity levels to determine that his alum dosage was correct, remembering that 1 mg/l of alum reduces the alkalinity by 0.45 mg/l.

TABLE 4-4 OPTIMIZING pH FOR COLOURED WATER

TREATABILITY
COAGULATION TESTS

TURBIDITY	2.4	J.T.U.
COLOUR	55	HAZEN
pH	7.7	
FLOC TEMPERATURE	64°F	
ALKALINITY	50	MG/L
HARDNESS	58	MG/L
IRON	0.1	MG/L
CHLORINE	2	MG/L

DATE September 1973
LOCATION Northern Ontario
RAW WATER ANALYSIS
RUN NO. 1

SOURCE Wet River

CHEMICALS					pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS							
JAR #	MG/L	MG/L	MG/L	MG/L	* INITIAL	FLOC	SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L	
1	40				7.7	6.7	fair	small	fair	2.3	1.6	6.7	10	0.4	<.05	32	57	
2	50				7.7	6.5	fair+	small+	fair	1.4	0.8	6.5	8	0.18	<.05	27.5	57	
3	60				7.7	6.3	good	good	good	1.0	0.35	6.3	< 5	0.08	<.05	23	56	
4	70				7.7	6.15	good	good	good	1.0	0.3	6.2	< 5	0.06	<.05	18.5	56	
5	80				7.7	6.0	good	small	good	1.2	0.35	6.0	< 5	0.06	<.05	14	56	
6																		

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING TIME SPEED G+/1000

2 MINUTES @ 100+ RPM sec^{-1}
25 MINUTES @ 25 RPM sec^{-1}
MINUTES @ RPM
SETTLING TIME 25 MIN

Table 4-4a

The operator was asked by Ministry personnel to carry out tests to determine whether sulphuric acid addition would reduce his alum requirements and subsequently his solids levels in his treatment plant. To see if this was possible, the operator carried out jar tests again. His results are summarized on Table 4-4b, Page 4-20. He repeated his best jar from Jar test #1 (60 mg/l alum) and reduced his alum feed by 10% in successive jars. He added 15 mg/l of sulphuric acid to each jar to lower the pH prior to alum addition. He found that he could reduce his alum requirements by 18 mg/l (30%) by the addition of 15 mg/l of acid and still produce similar effluent quality. This saving would not only reduce his alum cost but would reduce his sludge level by approximately 30% as well. The sludge, being higher in solids, would also probably be easier to treat. His periodic problems of floc carryover onto the filters would be less frequent than before. Once again the operator checked his coagulant dosages by measuring the effluent alkalinity. He remembered that 1 mg/l of alum reduces the alkalinity by 0.45 mg/l and 1 mg/l of sulphuric acid reduces the alkalinity by 0.95 mg/l.

TABLE 4-4 OPTIMIZING pH FOR COLOURED WATER

TREATABILITY
COAGULATION TESTS

TURBIDITY	2.4	J.T.U.
COLOUR	55	HAZEN
pH	7.7	
FLOC TEMPERATURE	64°F	
ALKALINITY	50	MG/L
HARDNESS	58	MG/L
IRON	0.1	MG/L
CHLORINE	2	MG/L

DATE September 1973
LOCATION Northern Ontario
RAW WATER ANALYSIS
RUN NO. 2

SOURCE Wet River

	CHEMICALS				pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS						
JAR #	ALUM MG/L	ACID MG/L	MG/L	MG/L	* INITIAL	FLOC	SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L
1	60	15			6.9	5.8	good	good	good	0.9	0.28	5.8	< 5	0.02	< .05	9	57
2	54	15			6.9	5.95	good	good	good	0.9	0.35	6.0	< 5	0.04	< .05	12	57
3	48	15			6.9	6.15	good	good	good	1.0	0.38	6.2	< 5	0.04	< .05	14	57
4	42	15			6.9	6.3	fair	good	good	1.2	0.40	6.3	< 5	0.07	< .05	17	57
5	36	15			6.9	6.4	poor	fair	fair	1.9	0.82	6.4	10	0.18	< .05	20	57
6	60	0			7.7	6.3	good	good	good	1.0	0.36	6.3	< 5	0.07	< .05	23	57

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING	TIME	SPEED		G+/1000
	2 MINUTES @	100+	RPM	sec^{-1}
	25 MINUTES @	25	RPM	sec^{-1}
	MINUTES @		RPM	
	SETTLING TIME		25 MIN	

Table 4-4b

Coloured Water - Alkalinity Problem

An operator in Northern Ontario had worked in his new Water Treatment Plant only six months. His old plant was little more than a chlorinated water pumping station. His new plant had complete facilities including sedimentation and filtration. During the fall, he began to get high residual aluminum levels. One particular day, severe "after floc" was showing up in the distribution system despite the fact that his effluent turbidity from his filter was 0.3 - 0.4 JTU. He read his notes carefully and decided to do some jar tests. His findings are listed on Table 4-5a, page 4-22. His present alum dosage is 40 mg/l with 10 mg/l of acid. He realized that either lower or higher alum dosages (Jar #1 and #4 was not the answer. His main problem was the high residual aluminum. This was due to the low alkalinity of the treated water. The low alkalinity of the treated water was due to the alum reducing it 0.45 mg/l per 1 mg/l of alum and the sulphuric acid reducing the alkalinity by 0.95 mg/l

per 1 mg/l of acid. He decided to carry out jar tests increasing the alkalinity of his raw water first. His choice of raising the alkalinity was lime or sodium bicarbonate. The results of these tests are outlined on Table 4-5b, Page 4-22. The operator knew approximately how much lime and sodium bicarbonate to add because he had the following chart.

1 mg/l of Sodium Bicarbonate increases the alkalinity by 0.6 mg/l
1 mg/l of Soda Ash increases the alkalinity by 0.94 mg/l
1 mg/l of Hydrated Lime increases the alkalinity by 1.26 mg/l

The results indicate that 14 mg/l of sodium bicarbonate raise the effluent alkalinity above 10 mg/l. The effluent residual aluminum has now been reduced to less than 0.1 mg/l and no "after floc" problems should occur.

The operator experienced trouble with the lime additions. (Jars #4 and 5). Even though the effluent alkalinity has been raised about 10 mg/l, there still are problems with high residual aluminum. This time, the high residual aluminum levels can be directly attributed to the high effluent pH. The lime raised the pH quite significantly (7.5 to 8.5 units) and the acid plus alum coagulant combination reduced it to a level of 7.4 units. This level was not low enough to remove either the colour or eliminate the high residual aluminum level. The operator tried a higher acid addition (Jar #5) to lower his pH further but still his effluent aluminum level was quite high. This was because the alkalinity was used up by the increased acid and he was right back to where he started. He concluded that to prevent "after floc" in his distribution system, he would have to add sodium bicarbonate. He also decided that since his raw water alkalinity levels changed almost daily at this time of year, he would include a treated water alkalinity test in his list of daily tests.

TABLE 4-5 SOLVING ALKALINITY PROBLEMS

TREATABILITY
COAGULATION TESTS

TURBIDITY	3.0	J.T.U.
COLOUR	40	HAZEN
pH	7.3	
FLOC TEMPERATURE	43°F	
ALKALINITY	30	MG/L
HARDNESS	35	MG/L
IRON	<.05	MG/L
CHLORINE	2	MG/L

DATE Fall

LOCATION Northern Ontario

RAW WATER ANALYSIS
RUN NO.

SOURCE River

	CHEMICALS				pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS						
JAR #	ALUM MG/L	ACID MG/L	MG/L	MG/L	* INITIAL	FLOC	SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L
1	20	20			7.3	6.5	slow	small	poor	3.4	1.5	6.5	20	0.40	<.05	2	
2	30	15			7.3	6.4	slow	fair	fair	1.8	0.8	6.4	10	0.43	<.05	1	
3	40	10			7.3	6.4	good	good	good	1.3	0.6	6.4	< 5	0.32	<.05	2.5	
4	50	10			7.3	6.4	good	good	fair	1.5	1.0	6.4	< 5	0.5	<.05	0	
5																	
6																	

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING TIME SPEED G+/1000

2 MINUTES @ 100+ RPM sec^{-1}
25 MINUTES @ 25 RPM sec^{-1}
MINUTES @ RPM
SETTLING TIME 25 MIN

Table 4-5a

TREATABILITY
COAGULATION TESTS

TURBIDITY	3.0	J.T.U.
COLOUR	40	HAZEN
pH	7.3	
FLOC TEMPERATURE	43°F	
ALKALINITY	30	MG/L
HARDNESS	35	MG/L
IRON	<.05	MG/L
CHLORINE	2	MG/L

DATE Fall

LOCATION Northern Ontario

RAW WATER ANALYSIS
RUN NO.

SOURCE River

	CHEMICALS				pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS						
JAR #	ALUM MG/L	ACID MG/L	Sodium Bicarbonate MG/L	LIME MG/L	* INITIAL	FLOC	SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L
1	40	10	0	0	7.3	6.4	good	good	good	1.4	0.6	6.4	<5	0.35	<.05	2.5	
2	40	10	14	0	7.5	6.5	good	good	good	1.2	0.5	6.5	<5	0.08	<.05	11.0	
3																	
4	40	10	0	8	8.5	7.4	poor	fair	fair	1.8	0.8	7.4	20	0.20	<.05	12.5	
5	40	30	0	8	8.5	6.6	fair	good	good	1.2	0.6	6.6	<5	0.40	<.05	0	
6																	

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING TIME SPEED G+/1000

MINUTES @ RPM sec^{-1}
MINUTES @ RPM sec^{-1}
MINUTES @ RPM
SETTLING TIME MIN

Table 4-5b

SUBJECT:

SURFACE WATER TREATMENT

PROCESS CONTROL

TOPIC: 5

Taste and Odour

- Causes
- Remedies

OBJECTIVES:

The trainee will be able to:

1. Understand the importance of taste and odour control in water treatment practice.

2. Identify causes or sources of taste and odour problems in water supplies.

3. Discuss two general methods of control for taste and odour problems:

   a) preventive

   b) corrective

4. List different chemicals used for taste and odour control and discuss the advantages and disadvantages of each chemical.

5. Define and give the advantages and disadvantages in:

   a) Breakpoint Chlorination
   b) Superchlorination
   c) Chloramination

TASTE AND ODOUR CONTROL

GENERAL

The presence of any unusual tastes in a public drinking water is likely to arouse some public reaction. The average consumer tends to associate them with impure or poor quality water even though that water may be sparkling clear and safe to drink. If any unusual tastes continue to persist in the water, he is likely to reject it and attempt to seek a more palatable water from another source which may not be sanitary and considered undesirable for human consumption.

Taste and odour control is an important part of the water treatment process. Because the consumers can detect and react to any sudden changes in the palatability of the water, the waterworks operator should be prepared to deal with these conditions as quickly as possible.

CLASSIFICATION

The senses of smell and odour are closely related. The complaints of objectionable tastes in water supplies are usually associated with odour. There are only four true taste sensations -- salt, sweet, sour and bitter. All other apparent sensations commonly referred to as tastes are actually odours even though the sensation may not be experienced until the substance has actually been placed in the mouth.

Substances which cause taste and odour problems in water supplies are usually present in very minute quantities. They are of such varied nature that simple laboratory methods cannot be readily used for their analyses. The most suitable method of detecting and measuring the intensities of tastes and odours in the water is probably by the use of one's own senses of taste and smell. These two senses are closely related and it is more convenient to use the sense of smell. This the principle of the Threshold Odour Test. **See Topic 14.**

It is almost impossible to determine and classify the different types of odours that can be experienced. Table 5-1 gives a qualitative description of some of the more common odours found in water supplies. It can be used as a guide to classify the type and determine the source of odour.

TABLE 5-1- GUIDE FOR QUALITATIVE DESCRIPTIONS OF ODOURS

CODE		NATURE OF ODOUR	DESCRIPTION (Odours of:)
A		Aromatic (spicy)	camphor, cloves, lavender,
	Ac	cucumber	lemon, *Synura*
B		Balsamic (flowery)	geranium, violet, vanilla
	Bg	geranium	*Asterionella*
	Bn	nasturtium	*Aphanizomenon*
	Bs	sweetish	*Coelosphaerium*
	Bv	violet	*Mallomonas*
C		Chemical	industrial wastes or treatment chemicals
	Cc	chlorinous	free chlorine
	Ch	hydrocarbon	oil refinery wastes
	Cm	medicinal	phenol and iodoform
	Cs	sulfuretted	hydrogen sulfide
D		Disagreeable	(pronounced unpleasant)
	Df	fishy	*Uroglenopsis, Dinobryon*
	Dp	pigpen	*Anabaena*
	Ds	septic	stale sewage
E		Earthy	damp earth
	Ep	peaty	peat
G		Grassy	crushed grass
M		Musty	decomposing straw
	Mm	moldy	damp cellar
V		Vegetable	root vegetables

Ref: Standard Methods for the Examination of Water and Wastewater, 12th Edition, p.306

CAUSE OF TASTE AND ODOUR

Tastes and odours in water supplies may result from any one or a combination of conditions. They are usually caused by the presence of dissolved gases and organic substances. In some cases, inorganic compounds such as those of mineral and metallic salts may impart tastes to the water at very low concentrations. However, organic substances are likely to be responsible for the presence of odours. Sources of material causing taste and odour problems may be:

1. Dissolved gases mainly hydrogen sulphide found in well supplies.
2. Biological growths such as algae, protozoa and slimes.
3. By-products of decaying algae and vegetation.
4. Contaminants from sewage effluents, and surface runoffs.
5. Contaminants from industrial waste discharges.
6. Growths of nuisance organisms in the distribution system.
7. Contact of water with painted surfaces such as bituminous linings of water pipes and storage tanks.
8. Excess quantities of chemicals such as chlorine and sodium chlorite used in the water treatment process.

CONTROL METHODS

There are two general methods employed in controlling tastes and odours in municipal water supplies--preventive treatment and corrective treatment.

PREVENTIVE TREATMENT

Preventive treatment means removing the source of tastes and odours and controlling the conditions so they do not develop and become troublesome. This may consist of taking steps to control growths of algae, aquatic plants and nuisance organisms in the water supply system. It may involve:

1. Control of aquatic plants in impounded areas and reservoirs.
2. Control of algae in open bodies of water.
3. Control of nuisance organisms in water.
4. Periodic cleaning of water treatment facilities at the plant.
5. Proper control of chemical dosages.

CORRECTIVE TREATMENT

Corrective treatment consists of removing the taste and odour-causing substances or changing their characteristics so they no longer produce any undesirable odours. This is usually done by physical and/or chemical methods.

Physical methods

These are designed to physically remove the odour-causing substances from water. This may involve one of the following:

1. Coagulation, flocculation, sedimentation, and filtration
2. Aeration
3. Adsorption with activated carbon

1. Coagulation, Flocculation, Sedimentation, and Filtration

   Coagulation, flocculation, sedimentation, and filtration all play an important part in water purification. However, they alone have a very limited effect on the removal of tastes and

odours caused by odour-producing substances. To produce palatable water, the odorous substances must be adsorbed or entrapped by the floc particles and removed from the water by filtration.

2. Aeration

Aeration, which brings the water into intimate contact with air, is used to remove hydrogen sulphide, carbon dioxide and volatile organic substances and improve the palatability of water. It was one of the earlier methods of treatment for odour removal. It was found effective in waters containing easily oxidized or volatile gases such as carbon dioxide and hydrogen sulphide. However, its usefulness for complete odour removal was found lacking because most of the dissolved substances cannot be easily destroyed by aeration alone. Aeration is achieved by spraying water into the atmosphere or by bubbling air into a body of water. Several devices are available for aeration. These include:

a) weirs over which the water cascades;

b) waterfall splashing over shelves or aprons;

c) spray nozzles;

d) diffusion tubes or plates etc.

3. Adsorption with Activated Carbon

Activated carbon is the most widely used and best known method for the control of tastes and odours in public water supplies. It has the ability to remove most of dissolved gases and organic substances that produce odours in water. This ability of one substance to attract, hold and accumulate another is known as "adsorption". Adsorption is primarily a surface phenomenon--the greater the surface area of the adsorbent, the greater its adsorptive power. Activated carbon is a form of charcoal which is prepared by a carefully controlled

combustion process to obtain a product possessing properties suitable for adsorbing taste and odour-causing substances in water. It is usually available in powdered or granular forms.

a) Powdered Activated Carbon

Powdered activated carbon can be used in water treatment plants equipped with filters which can take it from the water after its application. Activated carbon in the powdered form is considered to be the most economical and efficient method of treatment. Its efficiency for taste and odour control is governed by the following conditions:

- required dosage
- good mixing facilities
- point of application
- time of contact

The required carbon dosage should be applied at a point where adequate mixing is available to disperse small dosages in large volumes of water. The water should be rapid and turbulent enough to distribute the particles throughout the entire body of water. Carbon should remain in contact with the water being treated for at least 15 minutes to provide maximum adsorption of taste and odour-causing substances.

Advantages

- It is the most effective method of taste and odour control.
- It acts as a coagulant aid.
- It can be used intermittently.
- It can be applied at various points in the plant.

Disadvantages

- It is dirty and dusty.
- Separate handling facilities are required.
- Good filtration facilities are required.

b) Granular Activated Carbon Filter

For many years, carbon filters have been used. Instead of adding it to the water, the water is passed or filtered through the beds of granular activated carbon resting on layers of pebbles and sand. These types of carbon filters are utilized mostly in bottling plants and food industries where consistency in the taste and odour quality is of paramount importance. In some cases they are employed more for removing undesirable chlorine tastes from the treated water.

Granular activated carbon filters are used extensively for public water supplies in Europe, especially in Germany. However, in Canada and the United States only few municipal plants have used them because the use of powdered activated carbon was more economical

Chemical Methods

Chemical methods are based on the use of chemicals which can oxidize or destroy the odorous materials or change their character in such a way that they will not change or add any flavours to the water. Depending upon the physical and chemical conditions of the water, each treatment method has varying degrees of success. The following treatment methods will be discussed fully:

1. Chlorination - Breakpoint chlorination
   - Superchlorination
   - Chloramination
2. Chlorine Dioxide
3. Ozonation
4. Potassium Permanganate

Chlorination

Chlorine is an effective method for taste and odour control when properly applied. It is the best known and most widely used oxidizing chemical for the following reasons:

- It destroys and controls the growth of algae and nuisance organisms in the water supply.
- It destroys odour-causing organic substances.
- It destroys hydrogen sulphide in the water very effectively.
- It prevents septic conditions from developing in the distribution system.

Advantages

- Chlorine is readily available at most waterworks plants and therefore the purchase of special feed equipment is not necessary.
- Chlorine is relatively inexpensive in comparison to other chemicals.
- Increased dosage of chlorine for taste and odour control provides better disinfection of water.
- Chemical dosage of chlorine can be very easily controlled and maintained on a continuous basis.

Disadvantages

- Proper control must be maintained at all times as excess chlorine in water may cause objectionable tastes.
- Chlorine may actually intensify odours if certain organic compounds such as phenols are present.

Free Residual or Breakpoint Chlorination

Chlorine is a powerful oxidizing chemical. It will react with many substances dissolved or suspended in the water. Unfortunately, chlorine compounds that are highly odorous may be formed with certain substances such as phenols. Increasing chlorine dosages will destroy many of these derivatives,including those from reactions with ammonia and other

nitrogen compounds. For example, a sufficient chlorine dosage will completely oxidize hydrogen sulfide so that it is no longer obnoxious.

Chlorine, by reacting with any substance present in water loses its oxidizing power. Hence, it is no longer available as a disinfecting agent. However, if sufficient chlorine is applied to react and oxidize all the substances in the water, any further chlorine will show up as free available chlorine residual.

Free residual or breakpoint chlorination is the addition of enough chlorine to water to satisfy the chlorine demand plus free available chlorine in the water. It can be used very effectively for taste and odour control.

Advantages

- It is a simple method of treatment which can be implemented in most waterworks without installation of any elaborate chemical feeders.
- It is a more effective method of disinfection.
- Free available chlorine residual is more persistent and will remain in the distribution system over a longer period of time.
- With proper application, some of the taste and odour-causing substances in the water can be removed or destroyed.

Disadvantages

- Proper control must be maintained at all times to avoid chlorinous tastes associated with excess dosages.
- Chlorine demand may fluctuate from time to time to changes in the raw water quality.
- This method is not always effective in combatting problems caused by certain organic compounds, e.g. phenols

Superchlorination and Dechlorination

Superchlorination is a variation of free residual chlorination. Chlorine is applied in excess of the amount required without any regard to the amount of chlorine residual produced in water. After treatment, the water contains a very high level of chlorine residual which may impart undesirable tastes. Therefore, it is necessary to dechlorinate or reduce the excess chlorine by the application of one of several dechlorinating agenst such as ammonia, sodium sulfite, sodium sulfate, sodium thiosulfate or sulphur dioxide. Sulphur dioxide is the most economical chemical for this purpose and therefore generally used. Granular activated carbon filter is also used for removing excess chlorine.

Superchlorination is employed for taste and odour control at waterworks where the raw water quality is subjected to fluctuations.

Advantages

- It ensures proper treatment in water supplies with widely fluctuating raw water quality.
- It is effective in plants with short detention periods.
- High chlorine dosages will enable complete destruction of microorganisms and odour-causing substances.

Disadvantages

- Additional equipment is required to apply dechlorinating agent.
- Large amounts of chemicals are consumed in the treatment.

Chlorine-Ammonia Treatment (Chloramination)

Chloramination (chloramine) treatment is another method used for reducing taste and odour problems caused by chlorination.

The chlorine reacts with the applied or natural ammonia in the water to form chloramines. Ammonia retards the oxidizing power of chlorine and prevents the formation of odour-causing chlorinated organic compounds. Because of this, objectionable tastes and odours are not likely to develop as rapidly in waters when small amounts of ammonia are available with chlorination.

Chloramines have been particularly effective in minimizing the development of severe tastes in water containing phenols. They can also insure the maintenance of a chlorine residual over a longer period of time in the distribution system.

For taste and odour control, ammonia is added to the water and mixed thoroughly before the application of chlorine. This prevents the chlorine from combining with organic substances to form any odour-producing compounds. In practice, the chemicals are usually applied in the weight ratio of five parts of chlorine to each part of ammonia.

Advantages

- It suppresses the development of chlorophenolic tastes.
- Higher chlorine residuals can be applied without any adverse effects.
- Chlorine residuals can be sustained in the distribution system for a longer period.

Disadvantages

- It is the least effective method of chlorination for eliminating taste and odour problems.
- Excess ammonia may encourage growths or organisms in the system.

Chlorine Dioxide

Chlorine dioxide is a powerful oxidizing chemical having 2½ times greater oxidizing capacity than chlorine. It has been used successfully in controlling "chlorophenolic" or "medicinal" tastes occurring in water supplies which are contaminated by phenols and other industrial wastes.

At room temperatures, chlorine dioxide is a yellow to reddish coloured gas with an irritating unpleasant smell. It is very unstable. It cannot be stored or transported. It must be used immediately after generation. At the water-works, it is produced by the action of acid or chlorine on sodium chlorite. In practice, a sodium chlorite solution and chlorine solution are fed into a specially designed reactor where they are mixed and the resulting solution containing chlorine dioxide is passed into the water system.

Advantages

- It is very effective in curing objectionable taste and odour problems caused by phenolic contamination.
- It is also useful as a disinfectant.
- It is more effective than chlorine against bacteria spores.
- It is useful for removal of iron and manganese.

Disadvantages

- Sodium chlorite is expensive.
- Both sodium chlorite and chlorine dioxide are hazardous chemicals and must be handled with caution.
- Careful control required in maintaining ratio of chemicals for generation of chlorine dioxide.
- It is not effective for control of other types of tastes and odours.

Ozone

Ozone is a highly unstable gas with very high oxidizing capacity. It is used primarily as a disinfectant for water supplies and for controlling tastes and odours.

At room temperature, ozone is a faint bluish gas with a pungent odour. It is produced artificially in a special electrical apparatus known as a ozonator. It is generated

by discharging a high voltage electrical current through a stream of dry air or oxygen. During the process, a very small portion of air or oxygen is converted into ozone.

Advantages

- No storage problem as ozone is generated as required.
- It is an effective disinfectant.
- It may improve colour while removing tastes and odours.
- By-products are not known to be odoriferous.

Disadvantages

- Costs of capital equipment and operation are high.
- Operating conditions must be carefully controlled.
- Its effectiveness is limited to certain taste and odour problems.
- Effectiveness of treatment cannot be monitored.
- It is a toxic gas.

Potassium Permanganate

Potassium permanganate is an oxidizing agent which can be applied effectively to remove earthy and musty odours produced by organic matter and biological growths. It is a bronze or dark purple, crystalline powder, but may also be available in large black or purple crystals having a blue metallic sheen. It dissolves in water producing a dark purple solution. It is capable of oxidizing and breaking down some of the odorous organics into harmless substances that will not yield any taste and odour-causing by-products when subjected to chlorination.

In practice, potassium permanganate is dissolved in water to give a solution of 0.5 to 2.0 percent concentration. The solution is then added to the raw water prior to or at the same time as the coagulant chemicals for thorough mixing.

The chemical dosage is determined approximately by simple jar tests. It is related to the concentration of potassium permanganate required to treat the sample of raw water just so that its characteristic pink colour will disappear within a given period of time. This period is usually between 1 and 3 mg/l.

Upon reaction with oxidizable materials, potassium permanganate is reduced and forms insoluble brown precipitate. If left in the water, unsightly discoloration and staining problems may occur. Therefore, this chemical can only be used in plants equipped with good coagulation and filtration systems.

Advantages

- It is non-toxic and has some disinfecting properties.
- It can be stored and handled with ease.
- It removes any soluble iron and manganese.
- It removes colour.
- It acts as a coagulant aid.
- It may improve sedimentation.
- It destroys some organics.
- It helps to control algae growths.
- It reduces the amount of chlorine required for disinfection.
- Only low dosages (1-3 mg/l) are required.

Disadvantages

- The plant must have good coagulation and filtration facilities.
- Proper control must be maintained at all times to avoid penetration of filters by untreated chemical.
- Improper use may give rise to objectionable stains in the water supply.
- It is effective only in controlling earthy and musty odours.

SUBJECT:

SURFACE WATER TREATMENT
PROCESS CONTROL

TOPIC: 6
Filtration

- Operational Problems
- Filter Maintenance Aids

OBJECTIVES:

The trainee will be able to:

1. Understand the problems encountered in filter operation including the causes, characteristics and remedies of filter breakthrough due to:
   (a) high suspended solids
   (b) inadequate flocculation
   (c) filter cracking
   (d) mudballs
   (e) gravel mounding
   (f) filter clogging.
2. Know the reasons for and the prevention of:
   (a) media breakthrough
   (b) negative head & air binding
   (c) temporary filter breakthrough
   (d) bacterial growth.
3. Understand the operation of the:
   (a) flow through turbidimeter
   (b) headloss manometer
   (c) media breakthrough devices
   (d) filter peeker
   (e) inspection routines.

FILTRATION

FILTER BREAKTHROUGH

Perhaps the most widespread problem in Ontario is filter breakthrough prior to terminal headloss. Breakthrough may be defined as a steady increase in filter effluent turbidity (or colour) as the filter time progresses. Depending on the influent characteristics and filtration rate, the breakthrough may appear as illustrated in Figure 6-1. Under normal operation, the turbidity will remain relatively constant until the filter reaches terminal headloss (usually 8 ft.). If breakthrough occurs, there is a steady increase in effluent turbidity. The slope of the effluent turbidity line (Figure 6-1) will be steeper if the raw water turbidity is higher or the filtration rate is higher.

If breakthrough occurs on a regular basis, the following problems can result:

1. Treated water turbidity above the Ministry's objective of 1 Ftu entering the home or industry.
2. Loss of chlorine residual in distribution system.
3. Possible bacteria growth in distribution system.
4. Tap water containing floc alarming the consumer.
5. A buildup of suspended matter causing constant maintenance of water meters and valves.
6. Possible clogging of fire hydrants.
7. Corrosion and red water formation.
8. Taste and odour and/or colour problems.
9. Coagulant fouling some industrial processes.
10. Loss in pipeline capacity.

Needless to say, these problems should be prevented so the consumer is provided with water of acceptable quality.

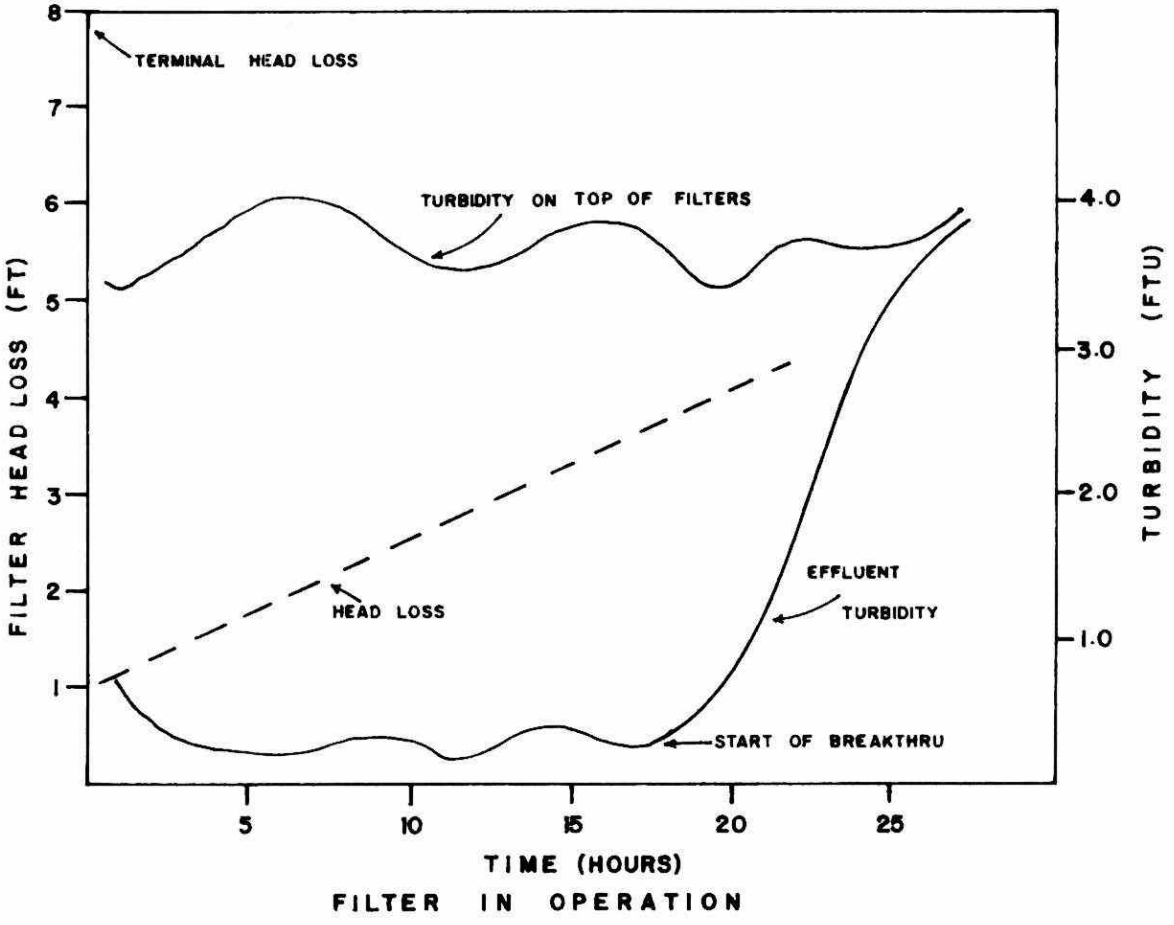


Figure 6-1 FILTER BREAKTHROUGH CHARACTERISTICS

Filter breakthrough may be caused by one or more of the following reasons:

1. High Suspended Solids
2. Inadequate Flocculation
3. Filter Cracking
4. Mudballs
5. Gravel Mounding
6. Filter Clogging

High Suspended Solids

1. Causes

   Suspended solids can be defined as suspended matter in the raw water plus the added coagulant(s).

   For plants using clarification or sedimentation tanks, high suspended solids entering the filter are usually due to:

   a) Incorrect dosage of coagulant and/or coagulant aid

   b) Hydraulically overloaded pretreatment system.

2. Operating Characteristics

   It should be understood that as a filter continues to trap suspended particles in the filter media, the head loss increases. The suspended matter is usually trapped in the upper half of the filter bed. But if the filter is allowed to run a longer length of time the solids will penetrate deeper into the bed. The objective of the operator is to have the filter reach its terminal headloss prior to these solids being trapped in the lower sand area. (The last deposit sites of the floc before the clear well.) This is illustrated in Figure 6-2.

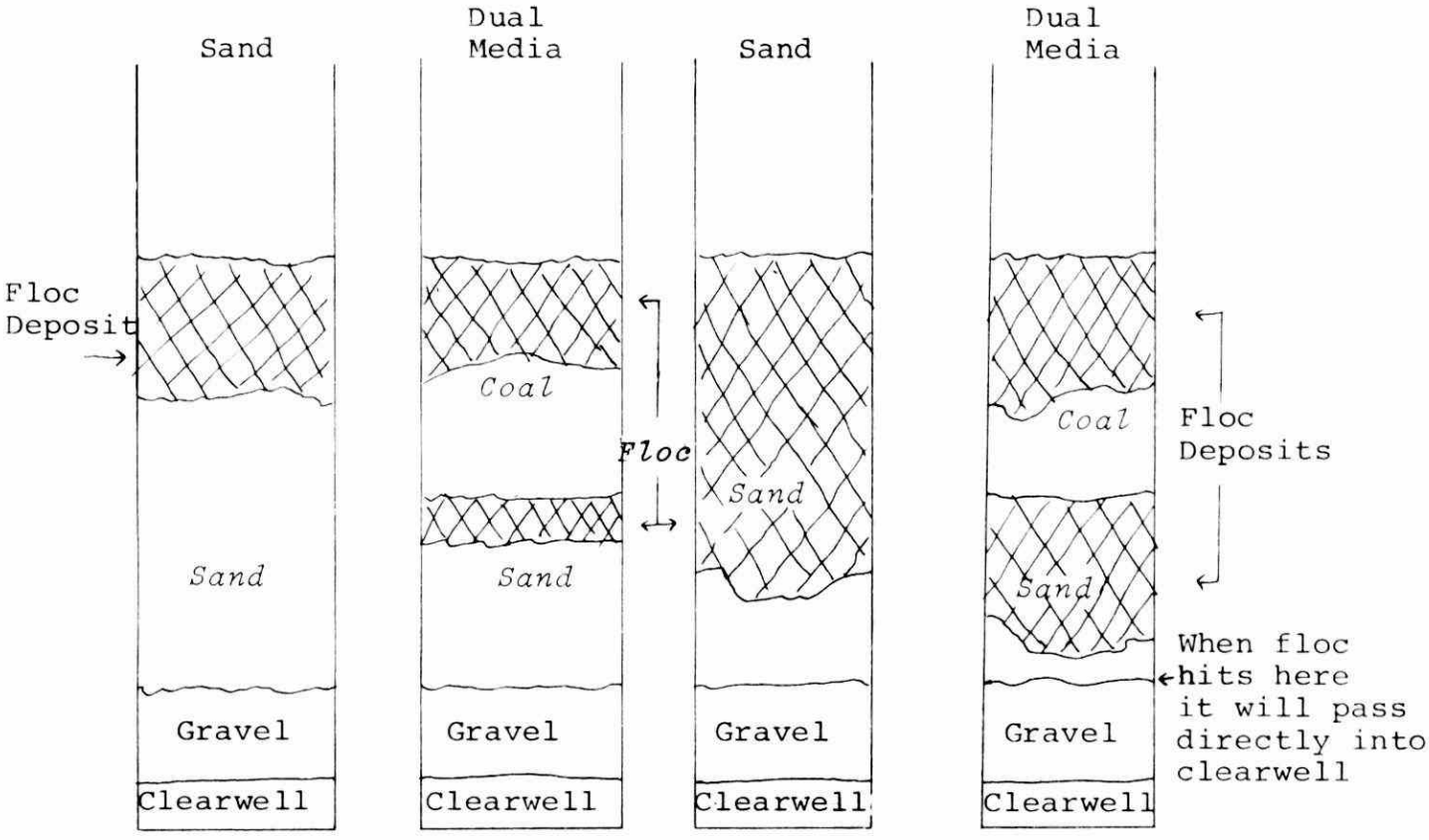


Figure 6-2 FLOC DISTRIBUTION IN A FILTER

If the solids in the flocculated water increase to levels such that there are too many floc particles fighting for deposit sites within the filter bed, the floc will be driven deeper into the bed. In extreme cases the floc may be driven deep into the sand layer resulting in the breakthrough of the filter before the filter reaches its terminal headloss. The reasons the filter did not reach its terminal headloss before filter breakthrough may include the following:

a) The floc is weaker than usual due to constant collisions of other floc particles during flocculation.

b) The large volume of floc in the upper stages of the filter bed promote channeling early in the filter cycle.

c) The floc is broken up within the filter bed because of the constant collisions of floc particles during their fight for deposit sites.

Whatever the reasons, if the condition of high suspended solids entering the filter persists, the plant operation will be severely restricted.

3. Remedies

Filter breakthrough can be eliminated in most sedimentation and clarification systems with proper pretreatment. This means the addition of the correct dosage of primary coagulants and coagulant aids. If the system is overloaded hydraulically, it becomes like a direct filtration system. In this instance, polymer should be added at the filter to strengthen the floc. The stronger floc will be trapped higher in the filter bed and the filter should reach terminal headloss prior to breakthrough.

Inadequate Flocculation

1. Causes

   In most cases, inadequate flocculation is caused by improper dosages of chemicals, inadequate mixing, or in some cases the wrong chemical being used.

2. Characteristics

   Underdosing alum will lead to fine particles of unagglomerated turbidity or colour passing through the filter. In some cases, the filter will work sufficiently well for a short period of time but premature breakthrough will occur at a low head-loss. Overdosing alum will lead to high suspended solids. If mixing is inadequate or the velocity through the valves and piping leading to the filters is too high (greater than 1.2 ft/sec) a weak or fractured floc may be formed and filter break-through may occur at a low headloss.

3. Remedies

   Adding the correct dosages of coagulant and coagulant aids should always take place. The use of jar tests should become a common plant practice. If the flocculation area is producing a weak or inadequate floc, experts should be consulted to provide the solution to this problem.

Filter Cracking

1. Causes

   Filter cracking is usually due to the filters being run an excessively long time between backwashes. A headloss device that is not working may result in the filters being operated too long.

2. Characteristics

   As the filter run time increases, the amount of suspended matter builds up in the upper part of the media. If the filtration rate is not able to pull the particles down into the bed or the

particles will not penetrate the bed, a cake forms on the surface. This cake causes a high headloss across the bed. Under certain hydraulic conditions, the cake will crack and water containing suspended matter will be channelled through the bed into the clear well. (Figure 6-3).

3. Remedies

If cracking is a common occurrence in the plant operation, a revised schedule of backwashing should be undertaken. All headloss devices should be checked and maintained in proper working order. The media should be examined for possible deposits and/or coatings of foreign material. It may be necessary to sample and size the media and replace it if it is found to be too small.

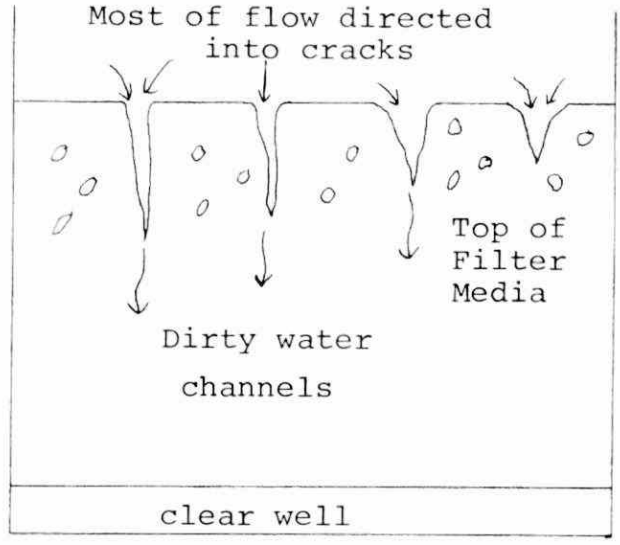
Mudballs

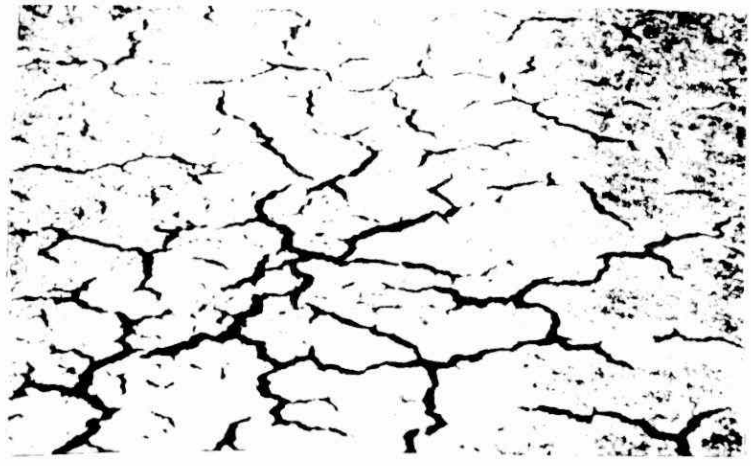
1. Causes

Mudballs are common in many plants but quite often their presence is unknown to the operator. They can be caused by low backwash rates which will result in a failure to remove much of the suspended matter trapped in the bed. Also, the lack of either surface washers on air scour assistance prior to backwash can promote mudball growth.

2. Characteristics

Mudballs often look like small pancakes. Their size can range from a fraction of an inch to several inches. If the surface wash device is not working or low backwash rates are used (less than 15 Igpm/sq.ft. for sand or dual media) the floc will coat or combine with some media particles and remain on the surface of the bed. After repeated washes, the particles will grow in size and weight. Over several weeks, they will penetrate the bed gradually and come to rest near the coal-sand interface or near the sand gravel interface.





Cracks in filter beds

Figure 6-3 FILTER CRACKING

They can prevent the operator from obtaining the best water possible due to destruction of the mudball during the filtration cycle. (e.g. if the operator had a clean filter, he should be obtaining an effluent of 0.2 Ftu turbidity. Mudballs may keep his best effluent quality in the 0.4 - 0.5 Ftu range.) Mudballs will also reduce the effective filter area causing a very high filtration rate in other areas of the filter which may promote breakthrough. (Figure 6-4).

3. Remedies

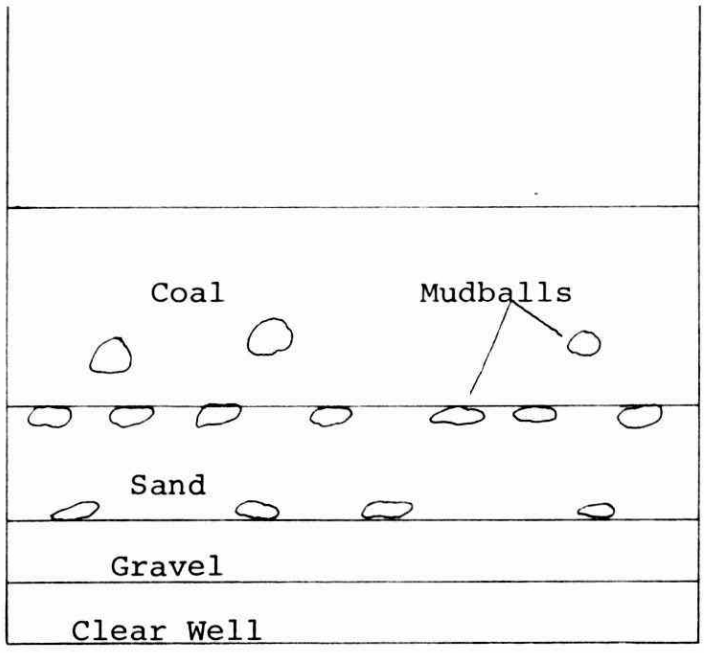
Mudballs are easier to prevent than remove. Keeping the surface wash on air scour devices in top operating condition is a necessity. Adequate backwash must be provided at all times. Expert help should be sought if the backwash rates are found to be inadequate. Many pressure filters which have no surface wash devices should be checked at least once per year for mudball growth.

The removal of mudballs is done by hand. The filters have to be dug up and the mud removed. Chemical means are time consuming, inadequate, and costly. Once an operator has been faced with the job of removing mudballs, he quickly establishes a regular checkup schedule to prevent future mudballs for the job is not a pleasant one.

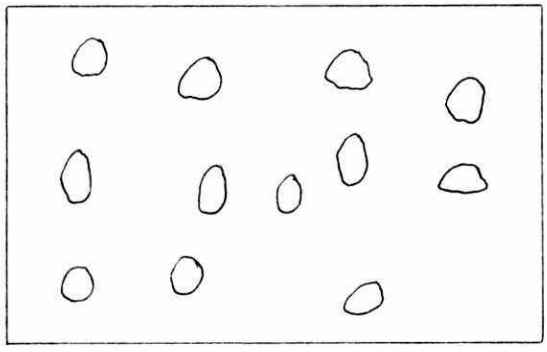
Gravel Mounding

1. Causes

Gravel mounding is where there is uneven and intermixed layers of the filter media. Mounding is often caused by "surge backwashing" which means that the backwash water is allowed to enter the underdrain area too quickly. The media is "blown" into other parts of the filter area. Although sand and coal will separate after mixing, damage done to the gravel layer is permanent. This problem sometimes is due to clogged or corroded underdrains diverting the backwash water into



Side View



Top View

Filtration Area
Reduced 10 to 50%

Figure 6-4 MUDBALL FORMATION

certain areas of the gravel. A pictorial diagram is given in Figure 6-5.

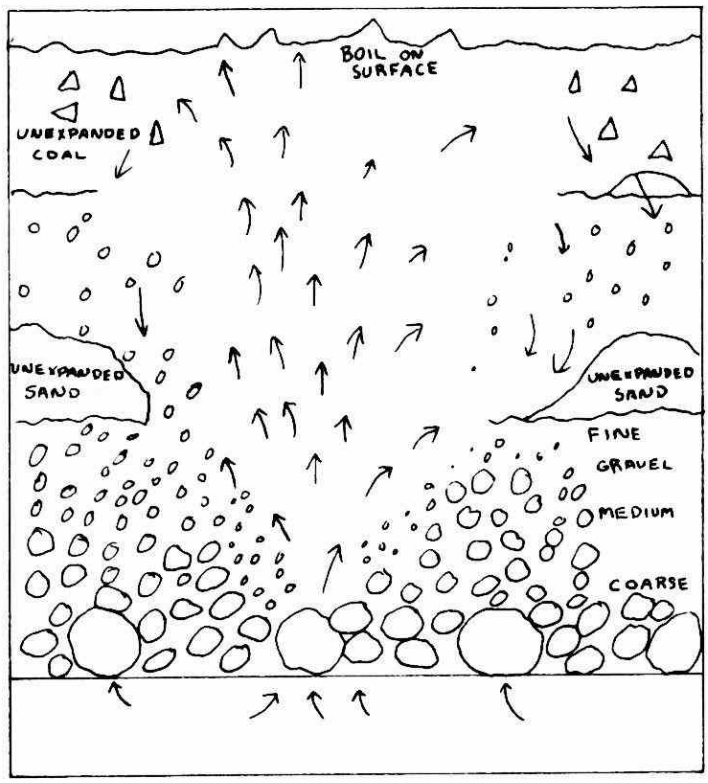
2. Characteristics

If the gravel is blown up into the media, there will be less resistance to the flow of flocculated water in that area. This short circuiting will result in the flocculated water passing through the mounded portions of the bed at filtration rates higher than the average filter flow. This may lead to early filter breakthrough. In addition, inadequate backwashing will take place and mudball formation is likely. An example of the gravel contours that might be encountered in a filter with mounding problems is illustrated in Figure 6-6. The media depths given in this figure can be found using a probe (long pole with a disk on the end) and using a low backwash water rate sufficient to suspend the sand and coal.

3. Remedies

The probe method, described above, is one of the best techniques available to determine if the gravel has shifted. If the gravel has shifted, the filter should be partially dug out and examined to determine if the coarser grades have been moved. If only the finer grades have moved the problem is not serious and can be corrected by the raking of the gravel layer during slow backwash or by adding extra gravel to the low spots. If the coarser gravel has shifted, the complete removal of the gravel layer will probably be necessary. A close examination of the underdrains should also be undertaken. Expert help should be consulted if the reason for the mounding is not apparent or if the underdrain system needs to be replaced.

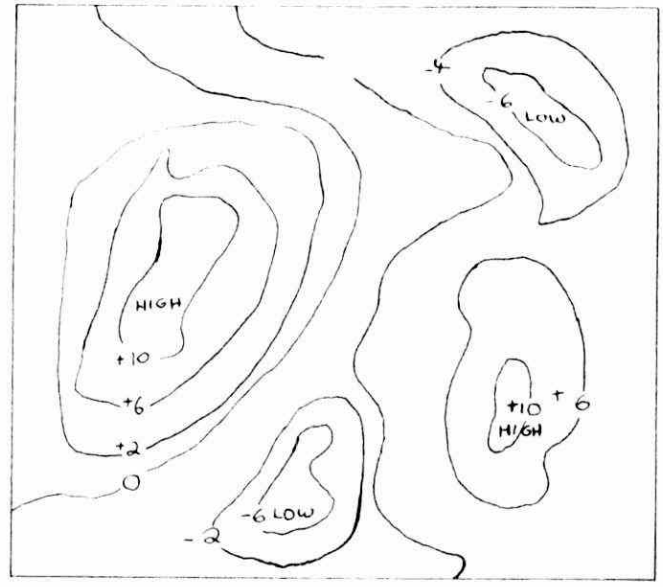
Yearly probe tests should be carried out as part of a regular maintenance program.



Most of the coarse gravel has been "blown" from the top of the underdrain.

Diagram of a gravel-media boil during backwash.

Figure 6-5 GRAVEL MOUNDING



Contours of Gravel

Contours are in inches above or below original gravel level.

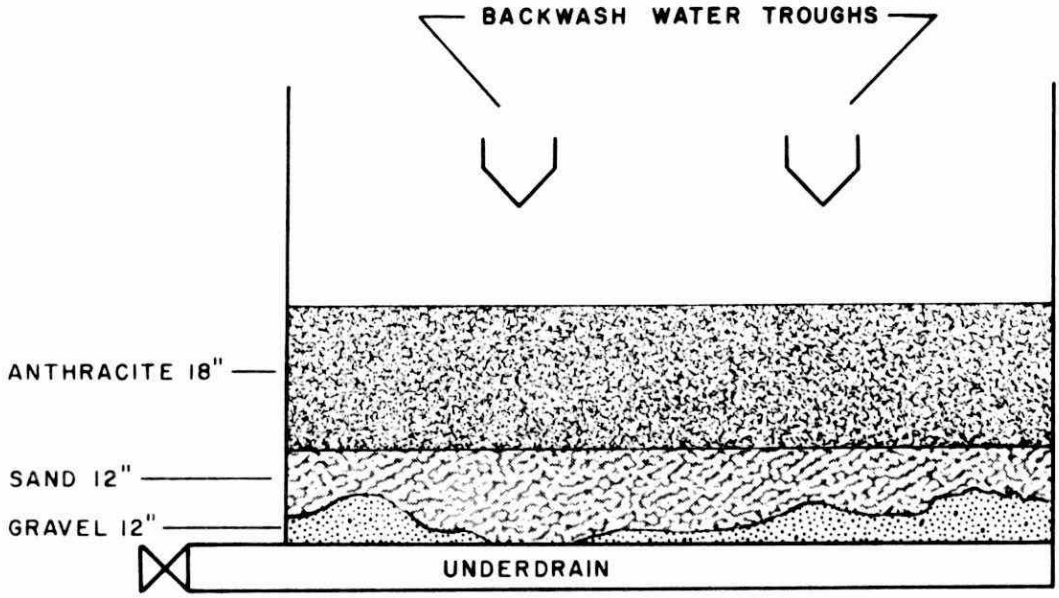


Figure 6-6 GRAVEL MOUNDING

Filter Clogging

1. Causes

   Filters can become clogged if *diatoms* are present. This microscopic form of plant life seals the surface of the filter media and may lead to filter cracking and severe channeling if the head loss device does not work properly.

   The filter could also be troubled with clogging if the media becomes encrusted with calcium carbonate. Calcium carbonate deposits may occur with the improper use of pH corrective chemical. (e.g. a highly localized concentration of sodium hydroxide). Calcium carbonate deposits may also occur in lime softening plants where the floc carryover coats the filter media.

2. Characteristics

   The obvious characteristic of calcium carbonate clogging is the incrustation on the filter media itself. It may result in channeling through the filter bed causing breakthrough. A high initial head loss through the freshly washed filter may be a characteristic of chemical encrustation.

   Diatoms in sufficient numbers result in shorter than normal filter runs.

3. Remedies

   Diatoms can best be removed through the proper use of Microstrainers or sedimentation/clarification facilities. Shorter backwashes than usual to minimize the strain on the backwash facilities may also have to be employed.

   Chemical cleaning of filter media encrusted with calcium carbonate may be necessary. It would not be advisable to use chemical means to clean the media without expert advice as permanent damage could be caused.

MEDIA BREAKTHROUGH

Most of the underdrains with the exception of the alloxite plates are usually found with graded layers of filter gravel separating them from the bottom of the filter media layer. The orifices in these types of systems are anywhere from 1/8 to 5/8 of an inch.

Normally, the graded gravel supports the filter bed, and distributes the flow in the filtration and backwash cycles. If mounding occurs, it is possible for some of the filter media to pass through the orifices into the clear well and possibly into the distribution systems.

Metal nozzles and strainers will corrode over the years. In some systems, the plugged orifices will cause an excess of water to be passed through non-plugged holes and mounding may occur. In other systems, the corroded nozzles may be eaten away and the majority of the flow pass through this area. Although plastic nozzles do not corrode, it is possible to crack or break them if probing with a filter rod.

Media breakthrough can cause improper seating of valves, foul up water meters, and on occasion can plug fog-nozzles employed for firefighting.

If you should suspect that filter media is passing through a filter, install sample taps (if not already present) on the filter effluent lines and attach socks to each tap. When the sample taps are opened all the water will pass through the socks. Other devices will be discussed in the Problem Stopper Section.

It is imperative that media breakthrough be stopped quickly. In most cases, the underdrain system has to be replaced. If the cause of the problem cannot be readily detected, apparent expert help should be summoned.

OTHER PROBLEMS

Negative Head and Air Binding

Some filtration plants have only 4 to 5 feet of water above the media surface and air binding problems may occur occasionally. Air dissolves in water at or near the saturation point. When the pressure is reduced to less than atmospheric pressure below the surface of the media, air comes out of solution, and air bubbles accumulate within the media. This may result in a marked increase in the headloss. If the operator is not aware of this problem, media may be lost in the early part of the filter backwash due to the violent agitation of the air being released from the filter media. In most of Ontario's plants troubled by air binding, the problem occurs in the spring season when the surface water is in the stage of "warming up" and is supersaturated with air. To prevent loss of media, care should be taken at the beginning of the backwash to partially drain the filter below the overflow troughs prior to starting the backwash water pumps.

Temporary Breakthroughs

Often in the hour to hour operation of the plant, the operator will find that his water demand fluctuates and it is necessary to change the filtration rate. Depending on variables such as the solids entering the filter box, filtration rate change etc, this surge of extra water through the filter will pull more solids into the clear well. An example of this is illustrated in Figure 6-7. Here we see that after the filter was in operation 13 hours, the filter rate was increased and the effluent turbidity rose to 0.4 Ftu from 0.1 Ftu. After it recovered to 0.1 Ftu, the filter rate was then increased again at hour 20, and the effluent rose to 0.5 Ftu. This rise in the effluent turbidity after the filtration rate was changed can be severe enough to cause a marked deterioration in the water

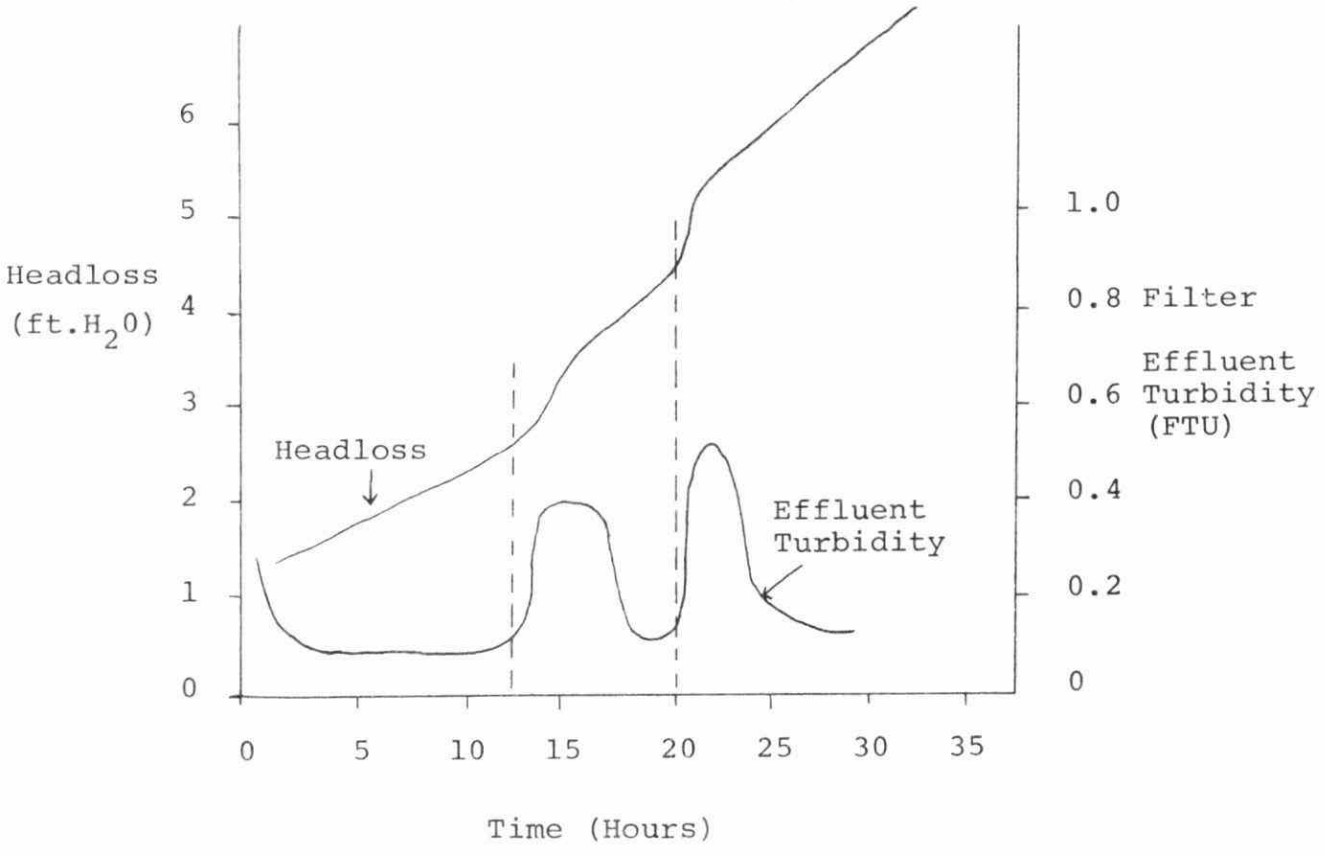


Figure 6-7 TEMPORARY FILTER BREAKTHROUGH

entering the distribution system. If possible, the filtration rate should be held as steady as possible throughout the length of the filter run. This may necessitate the shutting off of some of the filters during periods of low demand and returning them to service as the demand warrants their use. If this technique is not possible, the change in the filtration rate should be kept to a minimum. For example, if high demands are expected near the supper hour increase the filter rate an hour before the increase in demand and raise it slowly throughout the high demand period. This way, the amount of high filter effluent turbidity entering the distribution system can be minimized.

Bacterial Growth within the Filter Bed

If prechlorination is not practised, trouble may be experienced with filter clogging due to bacteria growth within the bed. One effective method of cleaning up such a bed is by heavy chlorination. Apparatus needed is a portable chlorinator, 150 lb, chlorine cylinders and a hand operated piping arrangement which is thrust down into the bed. The piping assembly is made up of a piece of one inch piping about six feet in length having a tee fitting at both ends. Two short lengths of one inch pipe about 14 inches long are threaded into the tee at one end of the six foot section. The outer ends of these are capped and a number of small holes are drilled through each length. This is the end of the assembly which is pushed down into the filter sand for chlorinating. To the tee at the opposite end of the assembly two more short lengths of pipe are fixed to form a handle. The outer end of one pipe is capped as before and the other end is fitted up to take a one inch hose connection. To carry out the cleaning operation, the filter influent valve is closed and water in the bed lowered until approximately four inches remain above the sand.

The effluent valve is also closed. The portable chlorinator is connected up to water supply and 150 lbs. chlorine cylinder. Discharge from the chlorinator is carried through one inch flexible hose to the handle end of the pipe assembly. Chlorine dose should be about 50 mg/l. The pipe assembly is lowered into the sand about two feet by a man standing in the wash trough and the chlorinated water is carried through the hose to the pipe assembly and exits through the small holes in the bottom pipe section as high velocity jet streams, cleaning and scrubbing the sand. The assembly is lowered, left for a few minutes and then lifted and moved along the bed in this fashion until the whole area has been so treated.

After this the filter is left as is for 24 hours, then given two or three washes and a chlorine residual test is carried out before placing the filter in operation.

Another method of cleaning sand is by passing it through an eductor, dumping it into another filter then repeating the process, returning the sand to its own filter. This will effectively clean the sand, but a number of filter washings will be necessary to get rid of the removed dirt. An eductor is illustrated in Figure 6-8.

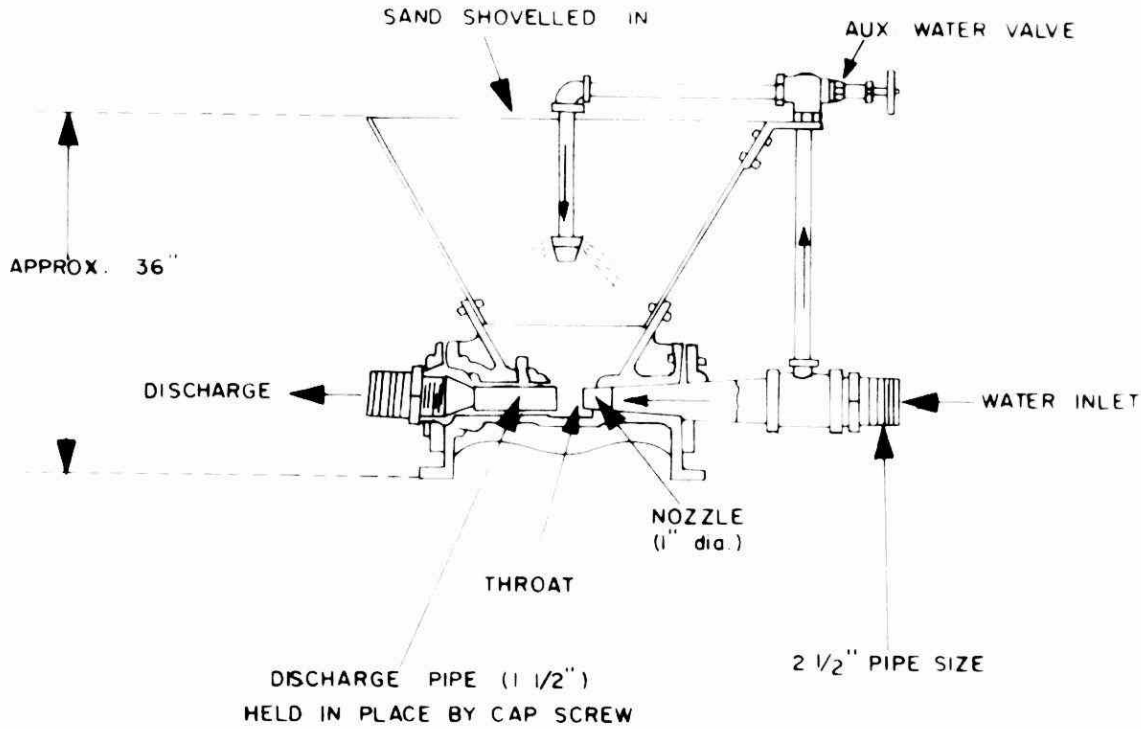


FIGURE 6-8 PORTABLE WATER JET SAND EDUCTOR

PROBLEM STOPPERS

Problems can be kept to a minimum for most filters in operation if the following devices and techniques are used.

1. Flow-through Turbidimeter
2. Headloss Gauge
3. Media Breakthrough Device
4. Filter Peekers
5. Inspection Routine

Flow-through Turbidimeter

A continuous readout of filter effluent turbidity with an alarm system can help the operator to catch filter breakthrough in its early stages. If a similar device is installed on the raw water, the correct coagulant dosage could be added at all times. The common practice of a delayed increase or decrease of the coagulant could be kept to a minimum using this technique. An example of a flow-through turbidimeter is given in Figure 6-9.

Headloss Gauge

The headloss measurement through a filter is important if the optimum filter operation is to be obtained. All headloss gauges and manometers should be maintained in proper working order. An effective device to determine the headloss through a gravity filter is a manometer tube. The test system is illustrated in Figure 6-10.

On a clean filter, the following headloss measurements would be expected.

Component	Depth	Headloss	Flow
Sand	12"	4-8"	3.0 Igpm/sq.ft.
Anthracite	16"	3-6"	"
Gravel	12"	1-2 1/2"	"
Underdrains	--	2-8"	"

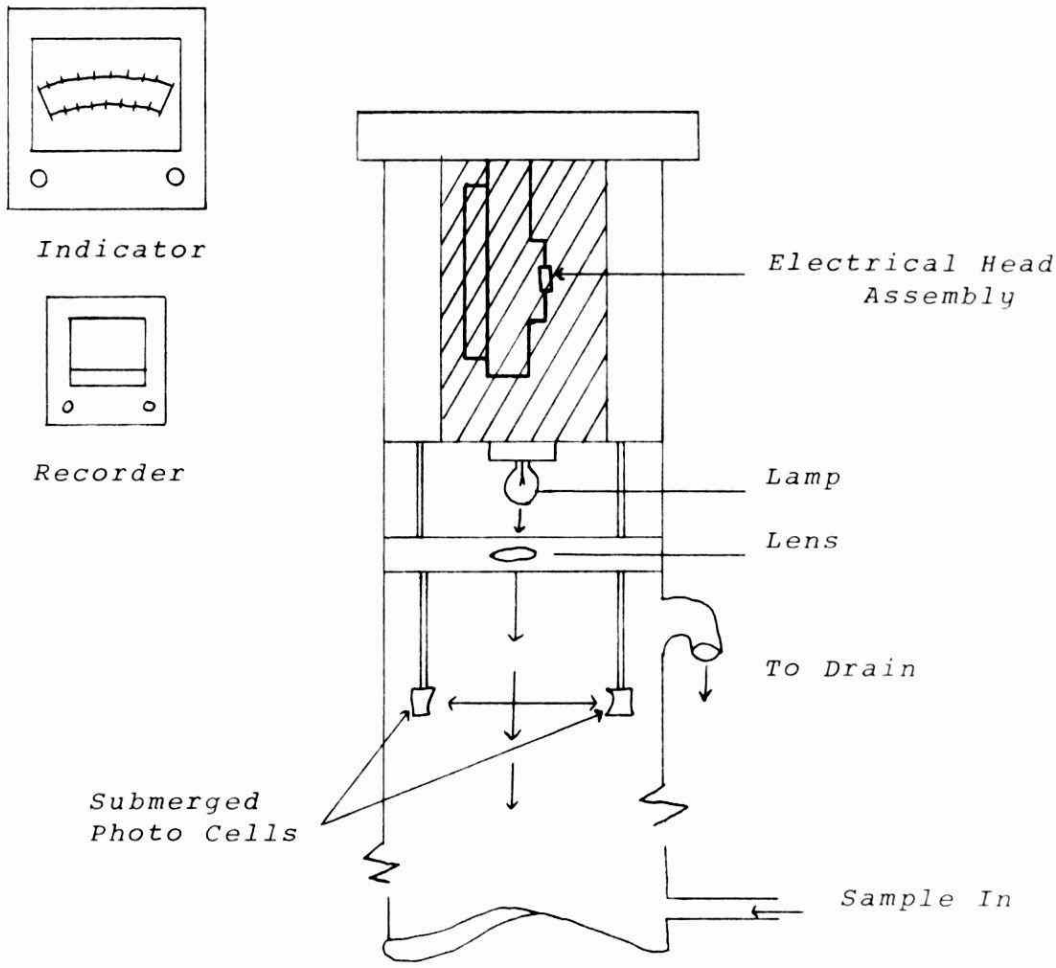


Figure 6-9 FLOW THROUGH TURBIDIMETER

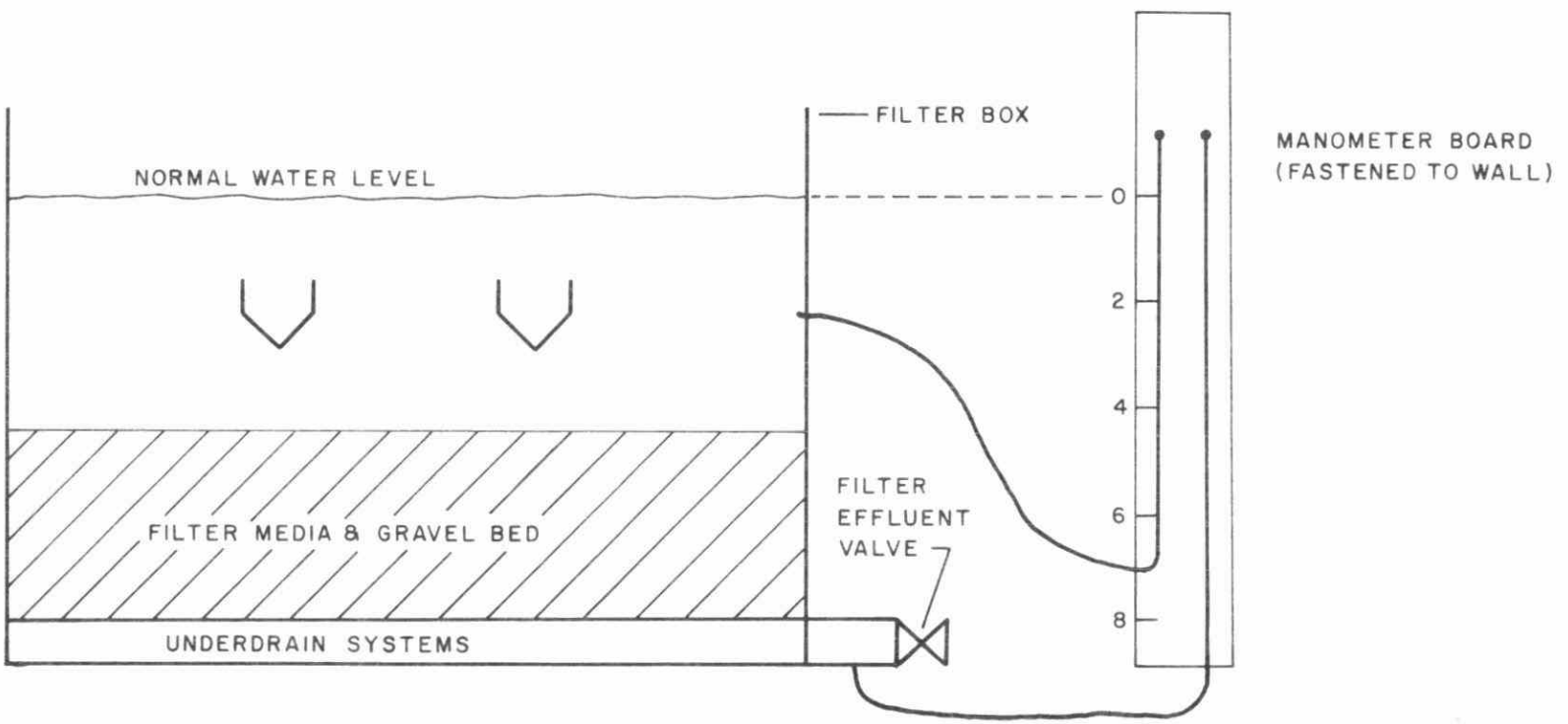


FIGURE 6-10 SIMPLE MANOMETER SYSTEM *(FOR HEAD LOSS DETERMINATION)*

Media Breakthrough Devices

A system to trap suspected media breakthrough should be set up on the discharge side of the filter. When there is a serious problem with gravel mounding or underdrain breakdown, filter sand and coal may appear in the clear well. The media detector, Figure 6-11, was developed to identify the seriousness of the problem and if several filters are in line, which filter is at fault. If there is media leakage the media will be deposited in the sock or cup. Filters that have been in service for a number of years sometimes pass sand periodically. If the passage of media continues, the filter may have to be rebuilt.

Filter Peeker

It is possible to look at gravel inside a filter to check for gravel mounding and also to check underdrains and to determine whether or not mudballs are present. This can be achieved with the use of a filter peeker (Figure 6-12).

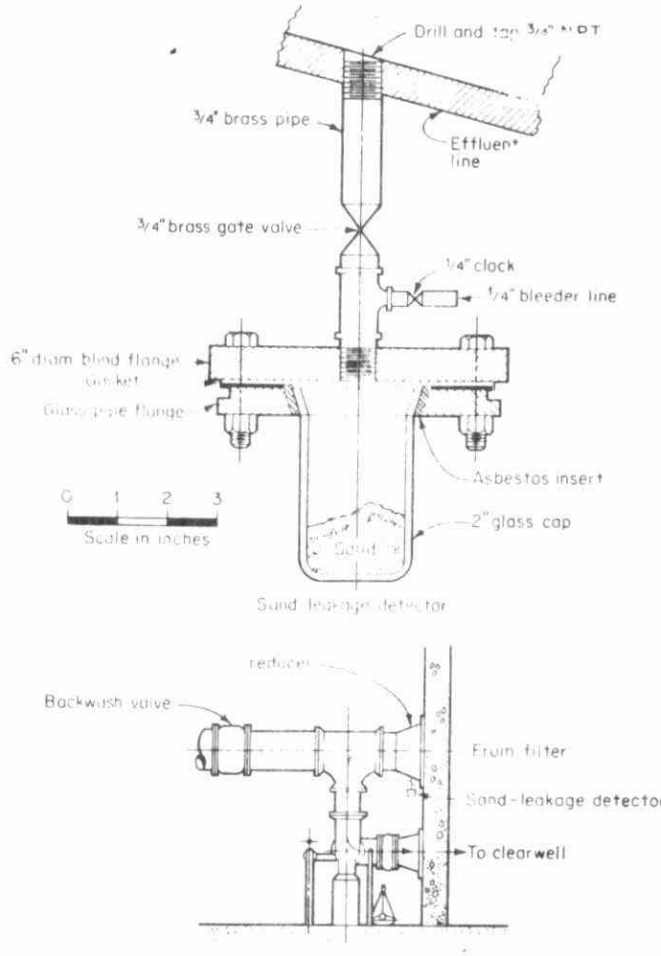
A filter peeker consists of a hollow copper tube with a periscope type hood and handle at one end to look through and a rectangular shaped conical hood at the other end with a glass plate and small lights inside. Flashlight batteries at the end with the handles provide a light source. This practical gadget can be constructed by most water works operators.

The filter peeker is inserted into the filter during a backwash and moved around by hand.

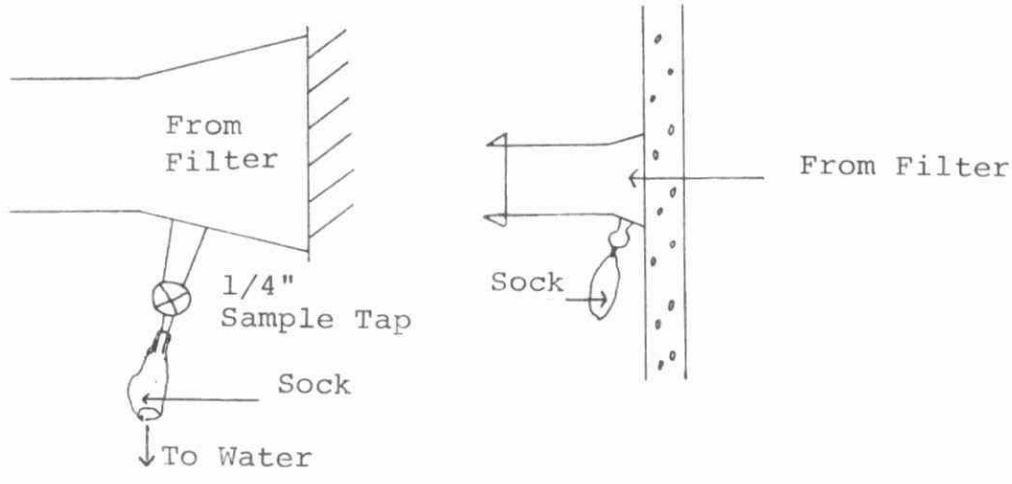
Inspection Routines

Regular inspection of all aspects of the filters will keep most problems minor by catching them in the early stages.

Inspection of the *Filtration Rates* can be easily determined by measuring the drop in water level over a given period of time. In this instance, the filter inlet valve is closed and the filter is placed into operation at a given



Effluent piping showing location of media-leakage detector.



SOCK TEST

Figure 6-11 MEDIA BREAKTHROUGH DEVICES

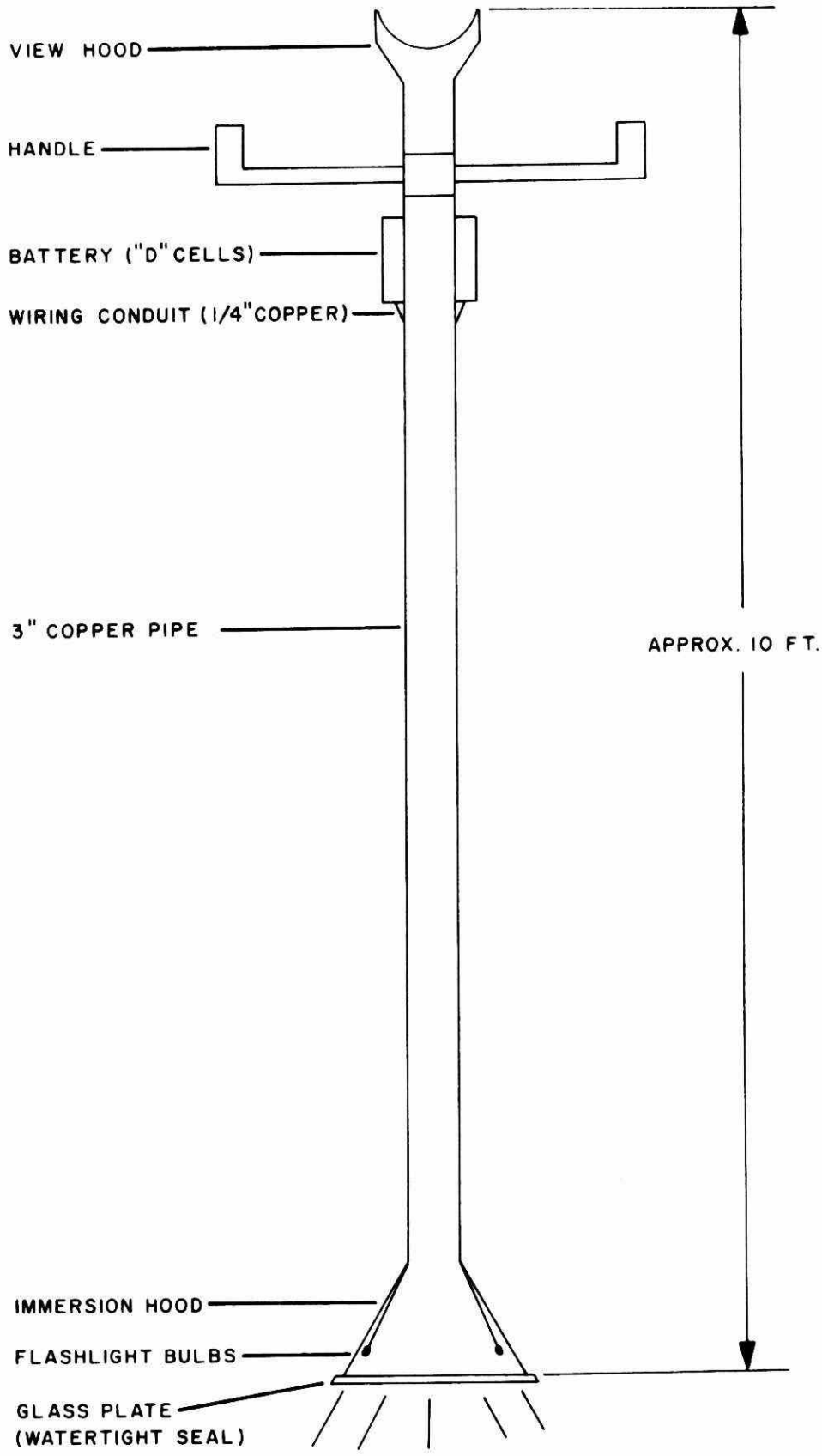


FIGURE 6-12 FILTER PEEKER

filtration rate. The drop in the level of water above the media is then measured (Table 6-1). Care must be taken to avoid measuring flow rates where the wash troughs would interfere with the water drop.

In a similar manner, *Backwash Water Rates* can be checked only this time the increase in water level is measured during the backwash stage. In pressure filters, the discharge to waste can be measured in a calibrated container over a given period of time and the wash rate can then be calculated.

The *Level of Media* should be checked at least once per year. To keep the operation of the surface scours or sweep efficient, the top of the media should be within 2 inches of the bottom of the sweeps. Loss of media during backwash is common in most plants and "topping up" of the filters often takes place every 2 or 3 years.

The *Gravel Distribution* should be checked once per year to keep any possible gravel mounding problems to a minimum. If difficulties in obtaining satisfactory flow rates and/or effluent quality persist, an inspection of the filter media for *Mudball* presence should be carried out.

Table 6 - 1

Chart to Aid in Detecting Flow Rates on Backwash Rates

Water Rise/Drop (inches per minute)	IGPM/Sq. ft.
1	0.52
2	1.04
3	1.56
4	2.08
6	3.12
8	4.15
10	5.2
12	6.2
16	8.3
20	10.4
24	12.5
28	14.6
32	16.6
36	18.7
40	20.8

SUBJECT:

SURFACE WATER TREATMENT

TOPIC: 7

Water Treatment Chemicals
- Characteristics
- Handling
- Feeding

OBJECTIVES:

The trainee will be able to:

1. name the chemicals most commonly used in treatment of water.
2. describe the proper storage and handling practice required for each chemical used in a water treatment plant.
3. name the four (4) classifications under which these chemicals fall.
4. describe the physical form in which these chemicals are marketed.
5. describe what each chemical is specifically used for in water treatment operation.
6. will know at what point in the treatment process each chemical is applied.
7. identify the types (categories) of chemical feed equipment used in water treatment plants.

WATER TREATMENT CHEMICALS

TYPES OF CHEMICALS

Many of the compounds used in modern water treatment plants have appeared in the last 20 to 25 years. Major advances would include the polyelectrolyte coagulant aids, the fluoride agents and chlorine dioxide. Others show a use-renaissance such as granular carbon, potassium permanganate and caustic soda. Still others enjoy, so to speak, a change in use direction, such as sodium silicate, chlorine and granular carbon. Others continue to be the mainstay compounds: alum, chlorine, soda ash, hydrated lime, and powdered activated carbon.

Noteworthy in the improvements affecting the delivery, feeding and storage of these chemical agents are the introduction of aluminum sulphate in liquid form, carbon slurry storage, lime slurries from bulk deliveries of hydrated lime and storage of saturated soda ash slurry in water treatment plants.

The chemicals for water treatment fall into one of the following four types:-

1. "Dry type" include the nonhygroscopic and slightly hygroscopic solids.
2. "Moist" or "Hygroscopic type" includes solids which absorb moisture rapidly.
3. "Liquids" include those materials which are liquid at normal temperature and pressure.
4. "Gases" include gases at normal atmospheric pressure although they become liquid under higher pressures.

Each of the four groups requires different shipping containers or units and different handling. Chemicals used in water treatment are listed in Appendix 1. The characteristics in descriptive sequence are: name of chemical, common names in parentheses, physical characteristics, chemical formula, density, solubility, hazard, basis for purchase.

HANDLING

Greater knowledge of materials together with the availability of new corrosion-resistant materials has facilitated the tasks of both the treatment plant designer and operator. Recommendations for the use of these materials for handling specific chemicals can be obtained, on request, from the manufacturer.

Chemicals for water treatment are shipped in a variety of containers. The choice of most convenient and economical packaging may depend to a large degree upon the extent of use and proximity of the plant to the supplier. There are various types of packaging in general use since manufacturers confine their packaging to chosen types. It is interesting to note the trend towards bulk truck delivery. Basic reasons for this trend include the variety of trucks available, reduced loading costs, improved delivery service, quick unloading, customer preference and resultant saving in chemical and attendant labour costs.

The variety of modern packaging and the different forms of transportation available make appreciable saving possible through selection of the various types. The small plant may not find it possible to accept bulk deliveries, while the moderately sized plant may find bulk delivery economical for some chemicals but not for others and the large plant will find economy in bulk delivery for nearly all chemicals. Size of plant does not preclude the possibility of appreciable saving, particularly where flexibility of chemical handling procedures has been provided in the design of the plant. Use of liquid chemicals in place of dry may prove to be more economical when all the above factors are considered. The cost of liquid chemicals delivered to the water plant may be no less, but there may be appreciable saving in operational costs. Use of unit hoppers for dry chemicals in place of bags eliminates packaging costs and products waste in handling and shipping, and reduces floor space for storage as well as the time and labour in handling.

STORAGE

All handling, storage or feeding areas should be maintained in a clean, dry, well-ventilated condition. Chlorine and other gases (Sulphur dioxide, ammonia) and gaseous products should be housed separately, with exterior vents provided with fans of sufficient capacity to force positive ventilation within a few minutes.

Since chlorine is heavier than air, exhaust fans should draw from near the floor. Ammonia gas is lighter than air, therefore, the exhaust should be from near the ceiling.

Areas for dry chemical storage need ample positive ventilation to maintain dust free air to protect the health of workers and avoid hazards of fire.

Normally dry bulk chemical is stored in bins or silos constructed of steel or concrete, of which there are innumerable designs. When the bins are constructed of steel, excellent control of inventory is provided by installed level indicators.

Another storage method for those chemicals which do not readily dissolve is "slurry storage". This method is particularly popular for activated carbon, and it is utilized somewhat for the calcium lines. Storage tanks for slurry may be lined and this is essential for carbon.

The common designs of storage bins are square, rectangular or round with an inverted truncated pyramid or cone forming the bottom and passing the chemical to the hopper of some type of feeder. The vertical sides of the main body of the bin generally extend upward to provide the required capacity.

Silos are large, cylindrical, freestanding storage units. They are utilized by plants which do not have sufficiently large storage internally, in order to receive bulk chemicals in truck-load quantity, or where the source or the transportation facilities make it necessary to carry a high inventory. They are completely weather-proof and

are provided with conveying and elevating equipment for transfer of the chemicals to the in-plant supply bins. This equipment is generally of the pneumatic type.

SELECTION OF CHEMICALS

Table 7-1 shows the phases of treatment in which chemicals listed in Appendix 1 are used. In selecting a particular chemical for a certain phase of treatment the operator must consider the Jar Test results and the facilities available at the plant. Some factors are:

1. In order to obtain good coagulation and efficient use of coagulants, it is important that the treatment be carried out at the correct or optimum pH. In the case of alum, this will be within the range of pH 5.8 - 7.5, though normally within 5.9 - 6.3 sometimes less.

2. The most desirable pH at which coagulation with alum should be carried out, using the "Jar Test" techniques, followed by laboratory filtration, is usually around 6.0. Aluminium hydroxide is soluble in both acids and alkalies, and if the pH is not correct there will be excess aluminium in solution in the final treated water.

3. If the water being treated has a high pH and high alkalinity, the required alum dose will not destroy sufficient alkalinity to appreciably reduce the pH. Acid may have to be dosed in addition, to bring the pH to within the optimum range.

4. On the other hand, if the water has a low alkalinity and low pH, alkali in the form of sodium bicarbonate, sodium carbonate or lime must be added to prevent the pH from being depressed too far by the effect of the required alum dose. In either case, it is important that the sequence of addition is correct, and that the first chemical added, is mixed and uniformly distributed to the raw water before the

second is added. In the case of coagulation at low pH, it is normal to add the acid or alkali before the coagulant, although under certain conditions it may be reversed. These latter cases are unusual and are determined during jar-testing.

5. Waters of low alkalinity and also low free carbon dioxide, are unbuffered, and the addition of lime (Calcium Hydroxide) would produce a rapid increase in pH. Under these conditions it may not be possible in practice to accurately control the dose of lime to maintain the pH within the desired range. A weaker alkali such as sodium carbonate or even sodium bicarbonate, may have to be employed, although coagulation would be improved by using the calcium alkali.

6. Ferric salts and chlorinated ferrous sulphate will form floc at high pH (i.e. above 8.3) and at low pH (between 4.0 - 6.0). The high pH treatment is often employed when the water has a low colour, or where colour removal and organic matter removal is unimportant, since at this pH level, organic matter removal is poor unless high coagulant dosages are used.

7. High pH coagulation at above 8.3 requires neutralization of the dissolved carbon dioxide and this must be carried out by the addition of lime. Caustic soda or sodium carbonate cannot be used. The optimum pH may vary from 8.3-9.3 and depends mainly on the initial alkalinity of the water. If alkalinity is high, the optimum pH will be low, and if the alkalinity is low the optimum pH will be high. In this treatment, it is absolutely essential that the coagulant be added and thoroughly mixed and dispersed in the water at the correct concentration before the addition of the lime.

8. Iron salts can also be used for organic matter removal at the low pH range, but the pH of coagulation is critical in order to ensure low residual iron in the

treated water. Although there are some municipal waterworks installations (not in Canada) employing low pH coagulation with chlorinated ferrous sulphate on coloured water, a number of industrial installations using ferric sulphate or ferric chloride for organic matter removal, in this country there is very little practical published information on low pH coagulation with iron salts. Laboratory research indicates that all the iron salts do not produce similar results under otherwise identical conditions, and considerably more research into this form of treatment is planned.

9. Coagulant aids such as activated silica or polyelectrolytes are used for the purpose of increasing the efficiency of coagulation and producing tougher and more rapidly settling floc particles. The most well known of these is activated silica. Activated silica is produced by the addition of sulphuric acid, aluminium sulphate; ammonium sulphate, sodium bicarbonate, or chlorine to a solution of sodium silicate so that a silica "sol" is produced. Considerable care should be taken in adding exactly the right amount of activating agent to the sodium silicate.

10. Polyelectrolytes, coming under the general heading of "polymers" (cationic, anionic or nonionic) must always be dosed as extremely weak solutions and sometimes applied at several separate points to avoid areas of local high concentration. At present, it is not possible to predict which of the many polyelectrolytes will be effective under any set of conditions. The selection of the right material is still a matter of experiment on the plant. In general activated silica or polymers are not used unless satisfactory results cannot be obtained without them.

TABLE 7-1

PHASES OF TREATMENT IN WHICH THESE VARIOUS CHEMICALS ARE USED

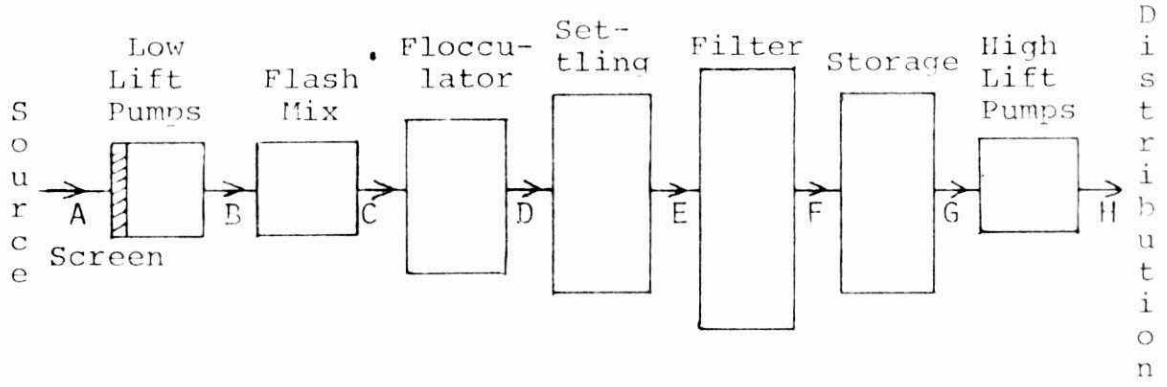
CHEMICALS	Coagulant or aid	Alkalinity & pH Adjustment	Disinfection	Dechlorination	Mineral Oxidation	Taste and Odour Control	Algae Control	Corrosion Control	Softening	Fluoridation
Activated Carbon				x		x				
Aluminum Sulphate	x									
Ammonia Anhydrous			x	x						
Ammonium Hydroxide			x	x						
Ammonium Sulphate	x		x							
Bentonite	x									
Calcium Hydroxide		x						x	x	
Carbon Dioxide		x							x	
Chlorine			x		x	x	x			
Chlorine Dioxide			x		x	x	x			
Copper Sulphate							x			
Ferric Chloride	x									
Ferric Sulphate	x									
Ferrous Sulphate	x									
Fluosilicic Acid										x
Hypochlorite, Calcium			x		x					
Hypochlorite, Sodium			x		x					
Ozone			x		x	x				
Pot. Permanganate					x	x				
Sodium Aluminate	x									
Sodium Bicarbonate		x								
Sodium Chlorite			x			x				
Sodium Fluoride										x
Sodium Hydroxide		x						x	x	
Sodium Silicate	x							x		
Sod. Silicofluoride										x
Sodium Sulphite				x						
Sodium Carbonate		x						x	x	
Sulphuric Acid		x							x	
Sulphur Dioxide				x						

The application points for chemicals related to a flow diagram are shown in Table 7-2.

TABLE 7-2 APPLICATION POINTS FOR CHEMICALS

CATEGORY OF CHEMICALS	POSSIBLE POINTS OF APPLICATION							
	A	B	C	D	E	F	G	H
Algicide	X				X			
Disinfectant		X	X		X	X	X	X
Taste and Odour	X	X	X		X	X		
Coagulants		X	X					
Coagulation Aids		X	X		X			
Alkali		X				X		
For flocculation			X					
For Corrosion control						X		
For softening			X					
Acidifier			X			X		
Fluorides						X		
Chloramine						X		
Dechlorinating						X		X

FLOW DIAGRAM OF WATER TREATMENT PLANT



With Solids - Contact Clarifiers, point C is same as point D.

EQUIPMENT

The different types of equipment being used for the feeding of chemicals in the form of gases, liquids or slurries, dry granular or powdered chemicals and unstable compounds, are numerous in design, and it is not possible to cover entirely this subject matter in the limited time allotted for this topic. However, to illustrate some of the equipment which is in use in Canada, the following is included:

1. Chlorinator

   Equipment of this type when used for chlorine, sulphur dioxide and ammonia, is called: a chlorinator, sulphonator and ammoniator. These dispensers can be used also for carbon dioxide and feature complete vacuum operation. The vacuum required for operation is produced by a water-powered ejector. The ejector discharge is a water solution of the gas being fed, permitting proper diffusion into the main body of water. Water to operate the ejector is obtained from the process or fresh water may be used. See Figure 7-1.

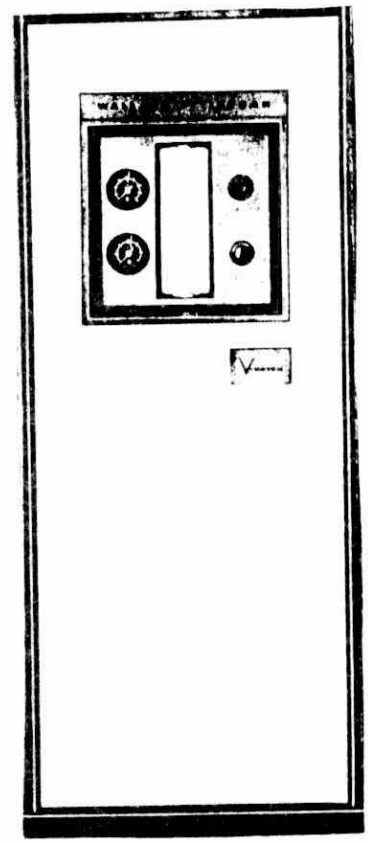


Figure 7-1
V - Notch Chlorinator
Courtesy, Wallace & Tiernan Inc.

2. Chlorine Dioxide Generator

This is a device for the continuous production of chlorine dioxide which is manufactured in the plant due to instability. By merging solutions of chlorine and sodium chlorite, chlorine dioxide is produced as the chemicals mix and flow through the generator.

The generator is a flanged glass chamber filled with porcelain Raschig rings. Separate inlet connections are provided for chlorine and sodium chlorite solutions at the base of the generator and an outlet connection for chlorine dioxide at the top. The generator is secured to a panel for easy well mounting. See Figure 7-2.

In operation, chlorine from a chlorinator is fed to one of the two inlets and a solution of sodium chlorite is fed by a diaphram pump to the other. The Raschig rings provide contact surface for the two chemicals as they mix and flow upwards. The glass generating chamber permits observation of the yellow colour produced by the presence of chlorine dioxide. See Figure 7-2a.

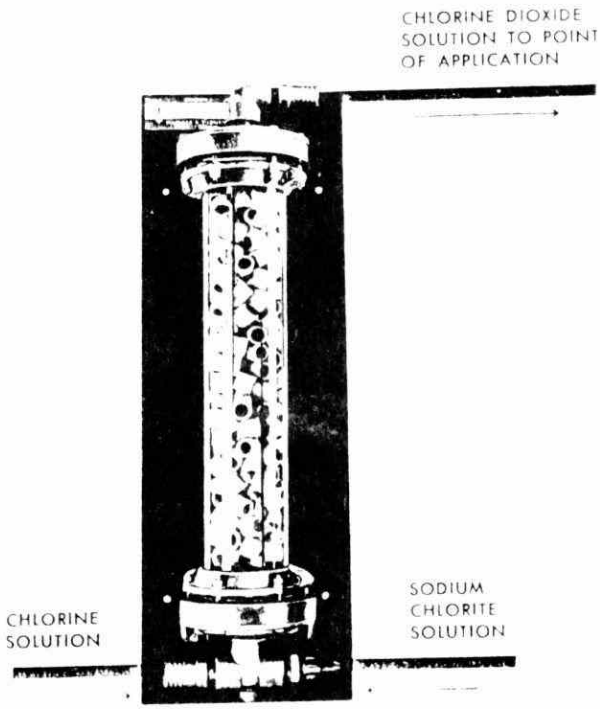


Figure 7-2
Chlorine Dioxide Generator

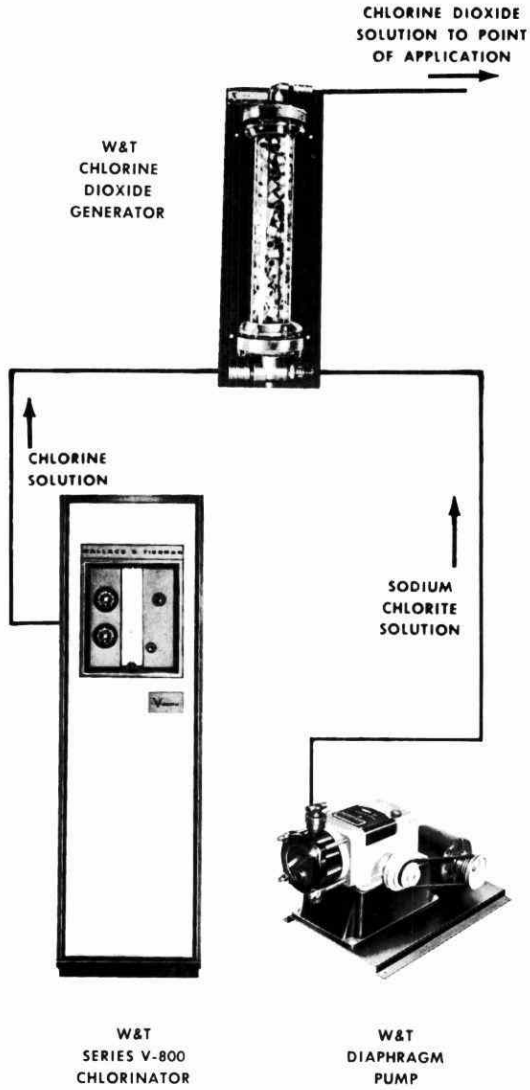


Figure 7-2a Chlorine Dioxide Generation System

3. Diaphragm or Metering Pump

This type of variable speed pump is suitable for the feeding of liquid chemicals or slurries. Both single and dual head models are available and include a 4 - step pulley for speed changes. A control knob adjusts stroke length and each head has its own indicating scale and control knob and by changing the belt on the 4 - step pulleys the discharge capacity of the pump is readily controlled. A flushing device is available also with the pump if required which is essential when feeding a slurry or a suspension. See Figures 7-3 to 7-5.

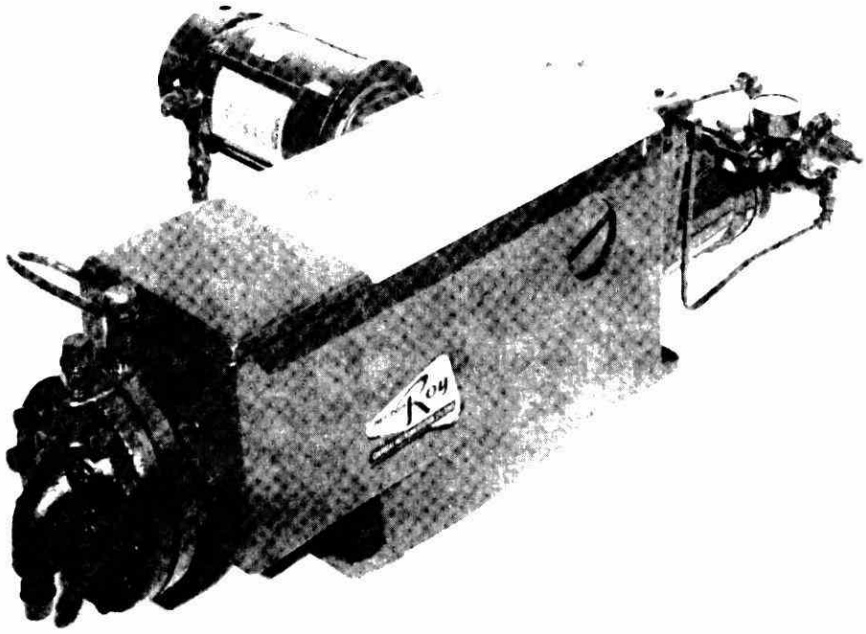


Figure 7-3 Diaphragm Pump Feeder (courtesy Milton Roy Co.)

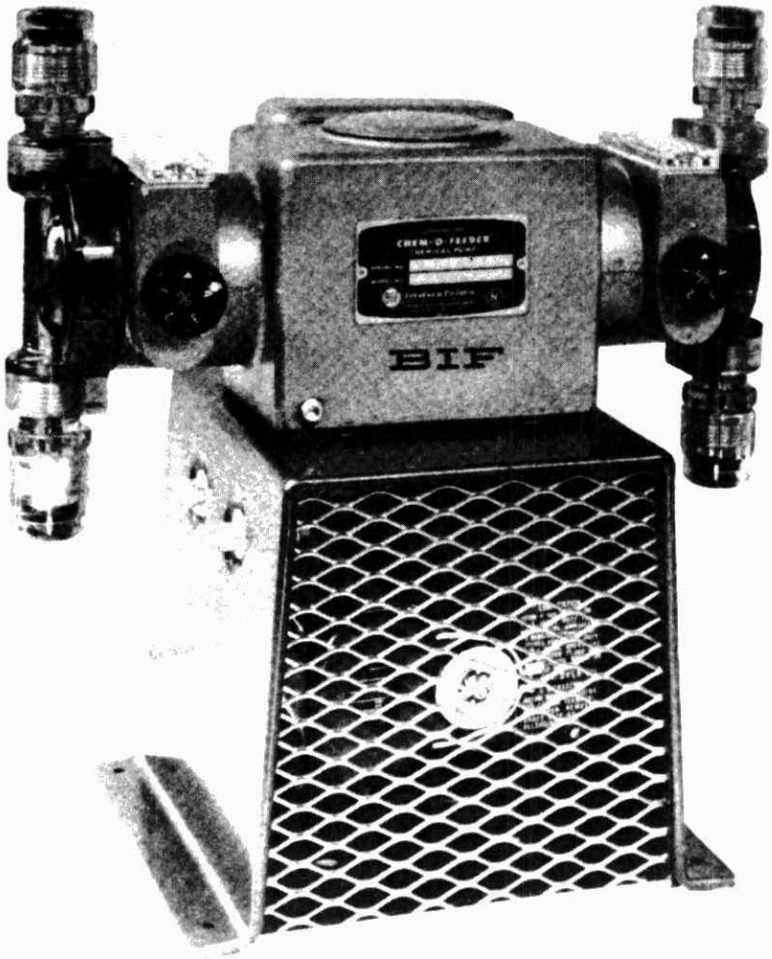
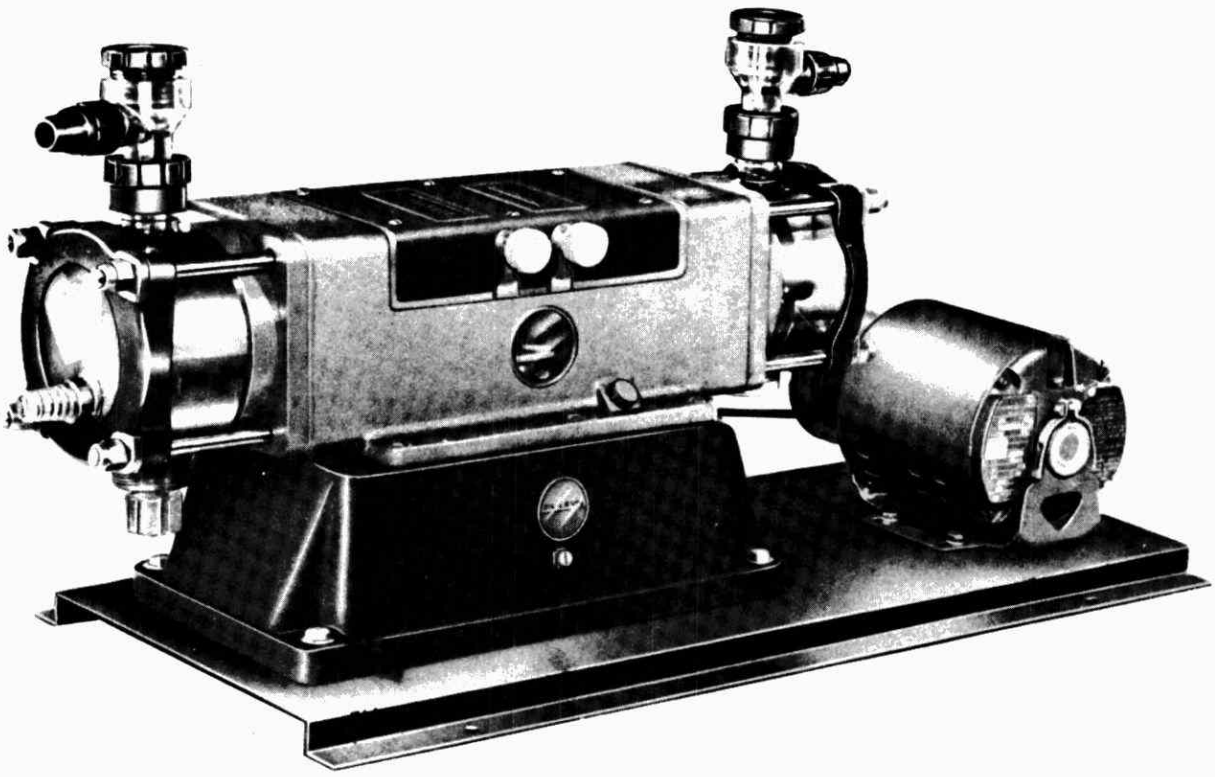


Figure 7 - 4
Chemical Solution
Feeder
Proportioneers
Courtesy
Omega Machine Co.

Figure 7 - 5
Chemical Solution
Feeder
Courtesy
Wallace & Tiernan



4. Rotodip Liquid Feeder

This type of feeder consists of a tank in which the chemical solution or slurry level is maintained by an overflow weir and a float valve; a dipper wheel with several dippers transfers predetermined quantities of liquid over a baffle to the discharge section and a variable speed drive rotates the dipper wheel. Controls for adjusting the speed of the drive to rotate the dipper wheel may be manual or automatic. Delivery of the wheel may also be changed by changing the liquid level. A totalizer is necessary since the amount fed is calculated by the number of rotations multiplied by the dipper wheel delivery per rotation.

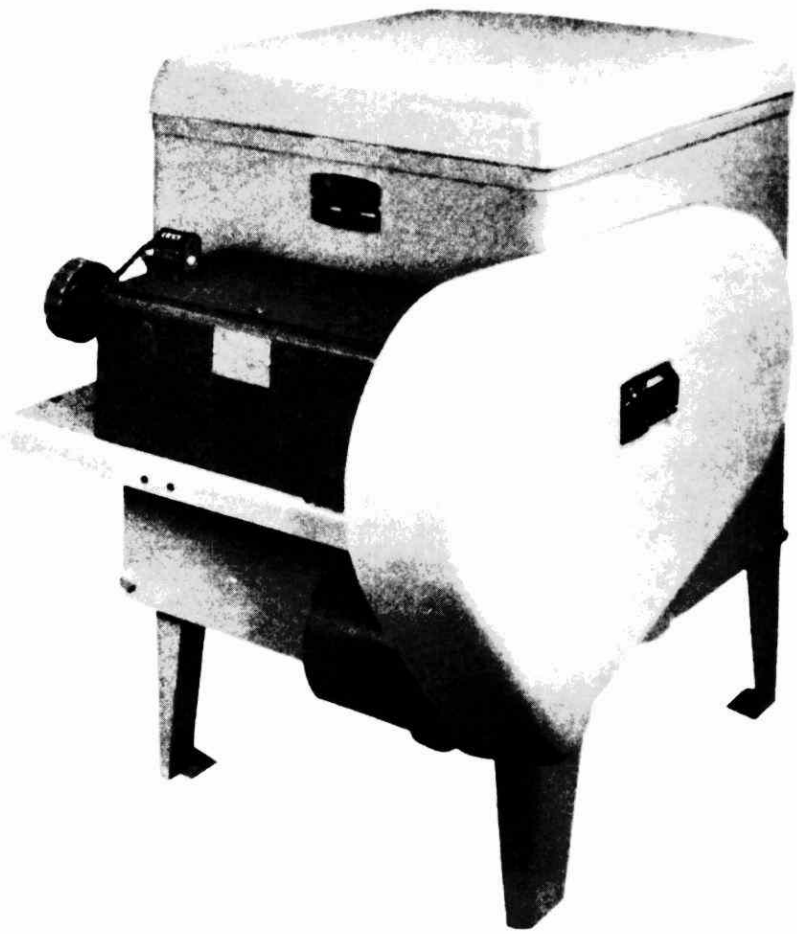


Figure 7 - 6 Rotodip Liquid Feeder
(courtesy Omega Machine Co.)

5. Chemical Dry Feeder

Equipment of this type is used for feeding free flowing dry granular or powdered chemicals. All dry feeding requires use of solution or slurry tanks, and this is included as an integral part of this unit with the feed mechanism mounted on the top and dropping the chemical directly into it.

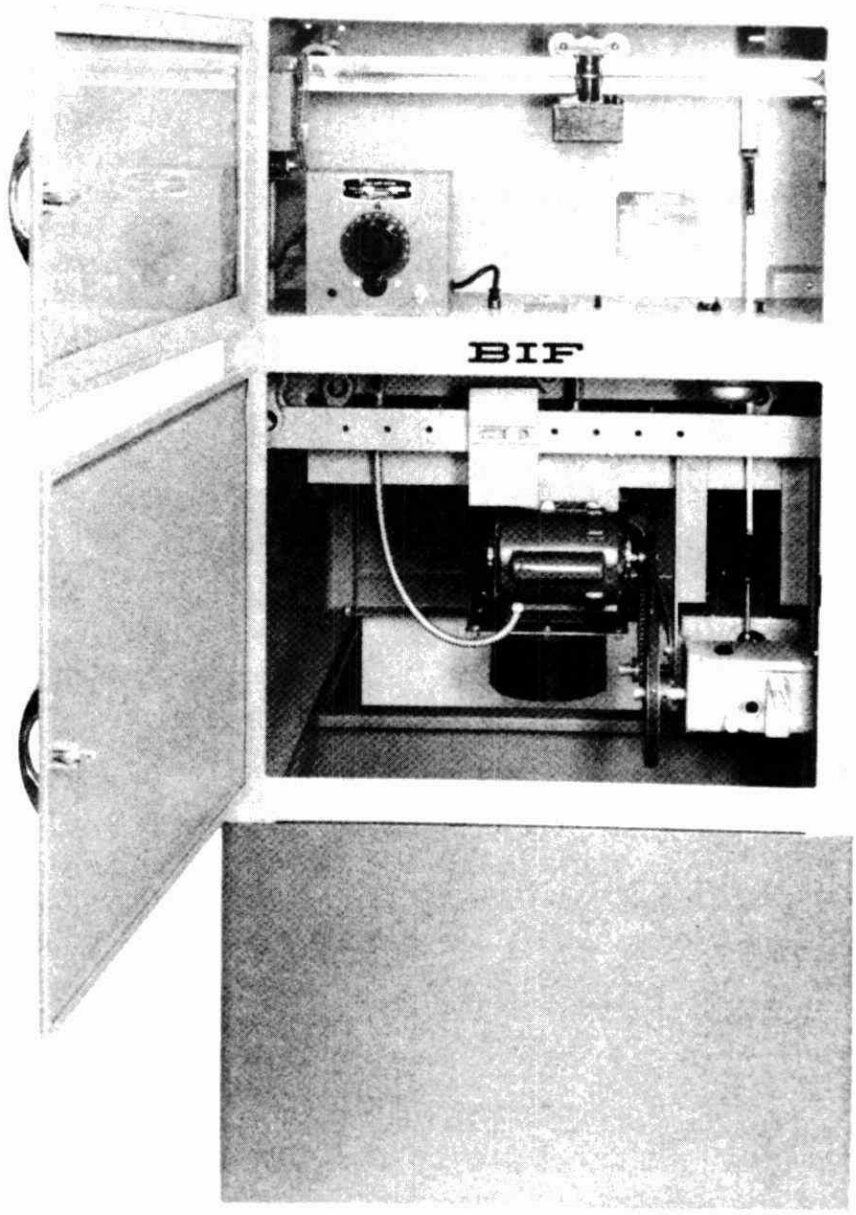


Figure 7 - 7 Dry Chemical Feeder
(courtesy Omega Machine Co.)

CHEMICALS USED IN WATER TREATMENT

1. Activated carbon, (Carbon) Dry, black, powdered or granular, highly porous and adsorptive; C; 15 to 20 lbs. per cubic foot; insoluble; dust and flammable; 95 per cent C, phenol absorption value of 20 to 27.

2. Aluminum Sulphate. (Alum) 1. Dry, crystalline, white to grey, lump to powder, slightly hygroscopic; $Al_2(SO_4)_3 - X(H_2O)$; 60 to 75 lbs. per cubic foot; 9.4 lb per gallon at 32°F., 10.0 at 60°F.; irritating and astringent dust; 17 per cent soluble Al_2O_3 or 9 per cent soluble Al: 2. (Liquid), slightly brownish; $Al_2(SO_4)_3 \times H_2O$; 8.3 per cent Al_2O_3 weighs 13.4 lb. per gallon; crystallizes at 20.°F. with content of 8.46 per cent Al_2O_3; skin irritants; 8.3 per cent Al_2O_3 or 4.25 per cent Al equals 6.5 lbs dry alum per gallon. (N.B. 'X' in alum formula can vary between 7 and 18. It denotes water of crystalization.)

3. Ammonia, Anhydrous. (Ammonia) Gas, colourless, compresses to liquid, pungent odour; NH_3; 38.5 lb per cubic foot of liquid at 60°F; 3.7 lb. per gallon soluble at 60°F.; respiratory irritant, explosive in air at concentrations of 16 to 25 per cent; 99 per cent NH_3.

4. Ammonium Hydroxide (Aqua Ammonia) Liquid, colourless, must be contained at below 80°F.; NH_4OH; 9 lb. per gallon weight at 29.4 per cent NH_3; solubility 29.4 percent NH_3 irritating fumes; 29.4 to 10 per cent NH_3.

5. Ammonium Sulphate. (Sulphate of Ammonia) Dry, grey to brown crystals to fine granules, hygroscopic and cakes; $(NH_4)_2 \cdot SO_4$; 60 lb. per cubic foot; 7 to 8 lbs. per gallon soluble; some irritating fumes and dries skin; min. 99.5 per cent $(NH_4)_2SO_4$ or 25 per cent NH_3.

6. Bentonite. Dry, pellets to powder, forming a colloidal solution in water; $(Al_2O_3.Fe_2O_3MgO)\ 4SiO_2.\ NH_2O$; ('N' refers to the number of molecules of water of crystallization) 60 lb. per cubic foot; insoluble; dust; a colloidal clay.

7. Calcium Hydroxide. (Hydrated lime, slaked lime, calcium hydrate) Dry, 200 to 400 mesh white powder, high angle of repose but when aerated flows like liquid, alkaline, very slightly hygroscopic; $Ca(OH)_2$; 35 to 50 lb. per cubic foot; solubility less than 0.2 lb. per gallon; dusty and burns skin; "high calcium", 86 to 96 per cent $Ca(OH)_2$, "dolomitic" less Ca but up to 30 per cent $Mg(OH)_2$.

8. Carbon Dioxide. (Carbonic acid gas) Gas, compresses to liquid, colourless, odourless, non-combustible and non-corrosive (also white, solid "dry ice"); CO_2; liquid 68.8 lb. and solid 97.5 lb. per cubic foot; solubility 0.36 lb. per gallon at $32^{\circ}F$. and 0.18 lb. per gallon at $68^{\circ}F$.; respiratory hazard; 100 per cent CO_2.

9. Chlorine. (Liquid Chlorine, Chlorine Gas) Gas, greenish-yellow, very pungent, non-corrosive when dry but very corrosive when wet, 463.4 volumes of gas compresses to 1 volume of greenish-yellow liquid; Cl_2; gas at $32^{\circ}F$ and 1 atmosphere = 0.198 lb. per cubic foot, liquid at $32^{\circ}F$ = 91.7 and at $68^{\circ}F$ = 88.0 lb. per cubic foot, at $50^{\circ}F$. solubility = 0.096 lb. per gallon; strong respiratory irritant, also poisonous; 99.8 per cent Cl_2.

10. Chlorine Dioxide. Gas, green-yellow, or when cooled becomes red liquid; ClO_2; 2.4 times the weight of air; solubility exceeds 0.1 per cent by weight; strong respiratory irritant, also poisonous; manufactured in plant due to instability.

11. Copper Sulphate. (Blue Vitriol, bluestone) Dry, blue crystals to snow, nonhygroscopic; $CuSO_4.5H_2O$; 75 to 93 lb. per cubic foot; solubility at 32° F = 1.92 and at 86° F. = 3.12 lb. per gallon; dust and also toxic; 99 per cent $CuSO_4.5H_2O$ or 25.2 per cent Cu.

12. Ferric Chloride. 1. Anhydrous is reddish-brown crystal, deliquescent and very corrosive; $FeCl_3$; 85 to 90 lb. per cubic foot; solubility unlimited; hazardous internally and will destroy shoes and clothing; 98 per cent $FeCl_3$ (34 per cent Fe^{+++}): 2. Crystals are deliquescent; $FeCl_3.6H_2O$; 60 to 64 lb. per cubic foot; 59 to 61 per cent $FeCl_3$ (20 to 21 per cent Fe^{+++}): 3. Liquid, at 60°F., 34 per cent $FeCl_3$ (11.6 per cent Fe^{+++}) weighs 12.9 lb. per gallon and 46 per cent $FeCl_3$ (15.7 per cent Fe^{+++}) weighs 14.4 lb. per gallon.

13. Ferric Sulphate. Dry, granular, reddish grey, free flowing, mildly hygroscopic, quite corrosive; $Fe_2(SO_4)_3.9H_2O$; 70 to 75 lb. per cubic foot; solubility 1 part in 1 part (50 per cent); dust, hazardous internally, will ruin shoes, 18 to 22 per cent ferric iron (Fe^{+++}).

14. Ferrous Sulphate. (Coppers, iron sulphate, sugar sulphate, green vitriol) Dry, green crystals which cake, very hygroscopic; $FeSO_4.7H_2O$; 65 to 70 lb. per cubic foot; solubility 2.4 lb. per gallon at 70°F; no special hazard; 55 per cent $FeSO_4$ (20 per cent Fe^{+++}).

15. Fluosilicic Acid. (Liquid Fluoride) Liquid, colourless to straw, quite stable, no appreciable viscosity; H_2SiF_6; 24 per cent = 12.159, 28 per cent = 12.56, 32 per cent = 12.975, 36 per cent = 13.379 per gallon; soluble in all proportions; vapours corrosive and respiratory hazard, slow irritant to skin; 24 to 36 per cent H_2SiF_6 = 19 to 28.6 per cent F.

16. Hypochlorite, Calcium. (HTH, Perchloron, Pittchlor) Dry, granular to powder or tablets, white to yellowish, hygroscopic; $Ca(ClO)_2.4H_2O$; 52.5 lb. per cubic foot; soluble to 3 per cent available chlorine; fumes poisonous and irritating to the skin; 70 per cent available Cl_2.

17. Hypochlorite, Sodium. (Chlorine bleach, bleach liquor) Liquid, light yellow, strongly alkaline, very active, NaOCl; 11.76 to 12.0 lb. per gallon; soluble in all proportions; slight fumes are irritating; flammable with materials such as oil, grease, paper, glycerine; 12 to 18 per cent available Cl_2.

18. Ozone. Gas, colourless, sweetish odour, very strong oxidant; O_3; 1.658 times the weight of air, soluble to 0.5 per cent by weight; inhalation must be limited; manufactured at the water plant due to instability.

19. Potassium Permanganate. Dry, purple, solid granules, hygroscopic, powerful oxidant; $KMnO_4$; 90 lb. per cubic foot; solubility at $32^oF.$ = 0.3 and at 68^oF = 0.6 lb. per gallon; poisonous, dust, also fumes from solution; 97 to 99 per cent $KMnO_4$.

20. Sodium Aluminate. (Soda Alum) 1. Dry, white to greyish, crystals, odourless, slightly hygroscopic; $NaAlO_2$; 45 to 60 lb. per cubic foot; soluble to 3.6 lb. per gallon at $68^oF.$, (contains 6 to 8 per cent insolubles); strong alkali causes skin burns; 46 to 55 per cent Al_2O_3 + 31 to 35 per cent Na_2O + 5 per cent NaOH: 2. Liquid, nearly colourless; at 27^o Be = 32 per cent $Al_2O_3.Na_2O$ + 9 per cent NaOH.

21. Sodium Bicarbonate. (Sodium Hydrogen Carbonate or Baking Soda) Dry; white powder; free flowing; odourless: slightly hygroscopic; $NaHCO_3$ - 130 - 138 lb. per cubic foot. Solubility at 32^oF = 0.69 lb per gallon and at 140^oF = 1.64 lb. per gallon; dusty no special hazard; 99 to 100 per cent $NaHCO_3$.

22. Sodium Carbonate. (Soda Ash) Dry, White powder, free flowing, slightly hygroscopic; Na_2CO_3; extra light, light and dense grades = 23, 35 and 65 lb. per cubic foot; at 32, 50 and 68°F. solubility is 0.7, 1.0 and 1.8 lb. per gallon; dust hazard, and solution is caustic; 99 per cent Na_2CO_3 or 58 per cent Na_2O.

23. Sodium Chlorite. 1. Dry, White to orange, flake or powder, slightly hygroscopic, powerful oxidant; $NaClO_2$; 50 lb. per cubic foot; at 41°, 63° and 68°F. solubility is 3.36, 3.84, and 4.56 lb. per gallon; fire hazard when dry on clothing or with organic matter or sulphur, may react violently with spark, heat, pressure or scraping; 78 to 85 per cent $NaClO_2$: 2. Liquid, tan to brown, slightly viscous; 40 per cent $NaClO_2$ weighs 14 lb. per gallon; 38 to 42 per cent $NaClO_2$.

24. Sodium Fluoride. (Fluoride) Dry, white crystals or powder, free flowing, slightly hygroscopic, sometimes artificially coloured blue; NaF; powdered 60 to 75 lb. per cubic foot and crystals 75 to 90; soluble to 0.42 lb. per gallon; dust hazard, and poison internally; 97 per cent NaF= 43 per cent F.

25. Sodium Hydroxide. (Caustic soda, soda lye) 1. Moist, white, crystalline, flakes to powder, quite hygroscopic; NaOH; weight varies; solubility at 32° and 68°F. is 2.88 and 5.28 lb. per gallon; causes serious skins burns, slight fumes respiratory hazard; 98.9 per cent NaOH equals 76.5 per cent Na_2O: 2. Liquid, 50 per cent solution weighs 15.24 lb. per gallon; 59 to 73 per cent NaOH available.

26. Sodium Silicate. (Water glass) Liquid, opaque, syrupy, alkaline solution; $2Na_2O.XSiO_2+H_2O$, with X varying from 1 to 7.5; weight varies; solubility 20 to 55 per cent; non-hazardous; various formulae available.

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 8

Tests to Determine Physical Parameters
- Colour
- Turbidity
- Solids

OBJECTIVES:

The trainee will be able to describe and/or demonstrate:

1. The use of the Lovibond Nesslerizer and the Hellige Aquatester for colour determination.

2. The use of the Hellige and the Hach turbidimeters for turbidity determination.

3. The methods of determining the total, suspended and dissolved solids in a water sample.

TESTS DETERMINING PHYSICAL PARAMETERS

GENERAL

The chemical processes that raw water may have to undergo in order to make it esthetically pleasing, reasonably palatable, and safely consumable, depend upon a number of variable chemical parameters which are responsible for giving each raw water its own individual characteristics. The diversity of types of water stems from the close contact it has had with varying geological basins, human pollution, and (decaying and growing) vegetation.

From the standpoint of the consumer, the physical parameters are the only ones he can readily observe with his unaided senses and upon which he bases his judgment on the effectiveness of the treatment that is given to the water that he consumes in his every day living. Thus this topic considers the laboratory procedures related to colour, turbidity and settleable solids. Taste and odour testing are considered in Topic 14.

COLOUR

Water is colourless by itself. When it leaches out high concentrations of iron and manganese from certain types of terrain, or organic substances from decaying vegetation, it takes on a brownish tint. Colour is a common constituent of some surface waters, and it can be attributed to the presence of non-toxic complex organic compounds.

Definition of Colour

When 1 milligram of Platinum present as chloro-platinate is combined with the appropriate amount of Cobalt Chloride, and they are dissolved in one litre of distilled water, then the ensuing colour from this standard is considered to be 1 HAZEN UNIT.

Analytical Technique for Colour Determination

1. Apparatus Required (See Page 8-4)

   a) Lovibond Nesslerizer, with discs containing glass standards

   OR

   b) Hellige Aquatester with discs containing glass standards.

   Both of these instruments use the same method, a straight comparison technique.

2. Procedure

   a) Fill one of the tubes supplied with the instrument to the 50 ml mark with the sample.

   b) Place it in the right hand compartment of the instrument (i.e. under that part of the disc without the glass standards).

   c) Fill the second tube with distilled water, and place it in the other compartment.

   d) Face the instrument towards a north window (or switch on the illuminating white light that can be obtained with the instrument, as an accessory).

   e) Rotate the disc containing the colour standards until a match is obtained. Note the number appearing in the aperture on the top of the instrument. This number is the result in Hazen Units.

3. Points to Remember

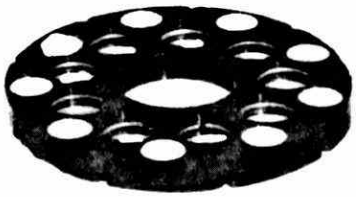
   a) When colour is caused by suspended matter, then an analysis sheet must append the comment "APPARENT COLOUR" directly after the result.

   b) If the colour is caused by a material that is in solution, then the words TRUE COLOUR should follow the result.

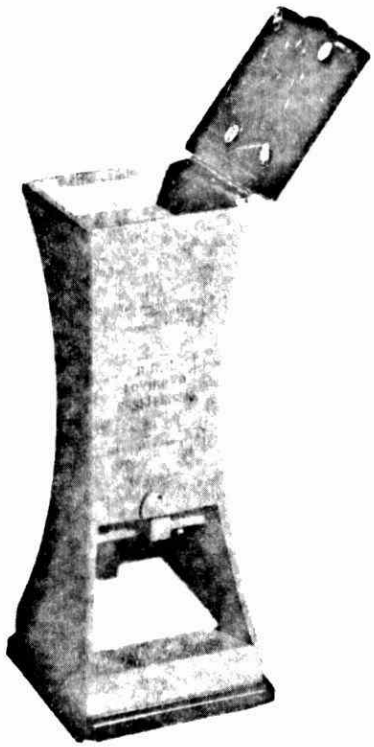
c) If a request is received for a true colour determination on a sample that obviously contains suspended matter which contributes in some degree to its colour, under no circumstances should the sample be filtered, because adsorption on the filtering medium might result in a lessening of the true colour. In such cases centrifuging of the sample is the only permissible way of separating the suspended matter from it.

d) Should the colour sample be darker than 70, which is the maximum reading that can be taken on the disc supplied with the instrument, it is permissible to make dilutions with good distilled water to bring the colour into a readable range. In this case, the result obtained must be multiplied by the dilution factor. However, in such cases discs with lighter ranges are available and their use is preferable.

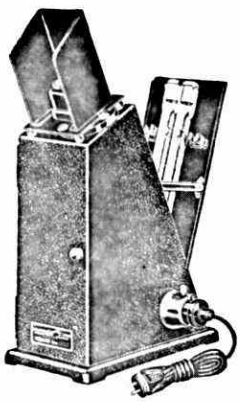
N.B. - Experience has shown us that the colour value obtained is often only valid for the pH at which the determination was made. If the pH is either raised or lowered, the intensity of the brownish colour very often becomes darker or lighter. A good discipline, therefore, demands that we should always include the pH figure when a colour determination result is submitted on a report.



COLOUR DISC



BDH LOVIBOND NESSLERIZER



HELLIGE AQUA TESTER

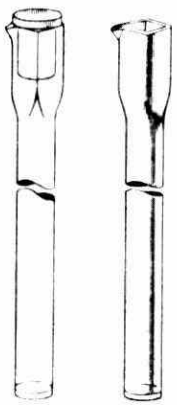


FIGURE 8-1 COLOUR DETERMINATION APPARATUS

TURBIDITY

Definition

Haze or turbidity in water is caused by suspended particles in it. The particles interfere with the passage of light through the water, and depth of visibility is curtailed in it. This depth of visibility decreases as the concentration of the suspended matter increases.

Units of Measurement

There are several units currently used for the expressing or recording of turbidity concentration. They are as follows:

- ppm Silver Chloride, ppm Barium
- Sulphate, ppm Celite, ppm Formazin,
- ppm Silicate, Silica Units,
- Absorptiometric Turbidity Units,
- Nephelo Unit, Helm Unit, and the
- Jackson Turbidity Unit sometimes called the Formazin Turbidity Unit, or Nephelometric Turbidity Unit (NTU), when Formazin or some other polymer is used as the calibrating material.

Based on findings, optical units seemed to be the most appropriate way of expressing turbidity concentration. The most misleading unit was ppm. The implication of this unit is that the weight of the suspended material causing the turbidity is actually known. This is certainly not true when a variety of materials compose the suspension and their percentage concentration of the total suspension is varying continuously. In such a case the relative densities of the materials together with their individual concentrations would have to be known at any given moment in order to arrive at a true ppm value; which would only be valid for that moment. The only time that the ppm scale is correct is when the material that has been used in calibrating the scale is precisely the same as the suspension of the sample being measured, and this must include the particle size distribution of the suspension.

Methods of Measurement

1. Absorptiometric

Measurement of the optical density of the sample at a wavelength that provides maximum sensitivity for this type of determination. See Figure 8-2 .

When a plant using Carbon Filters has a carbon leakage, the only way of measuring the concentration of this suspension is by using an Absorptiometer that has been calibrated with varying concentrations of the same carbon material.

Although the presence of a haze in water does not always mean that the water is unfit for drinking, it can be regarded as visually offensive, and it definitely presents an optical problem if not a health hazard. Thus, it can be readily recognized that optical units are a more meaningful way of expressing this parameter, in order to assess the magnitude of the problem.

2. Turbidimetric

Measurement of the depth at which a metallic disc just fades out of view in a liquid. See Figure 8-3 .

3. Nephelometric (Greek: Nephele-Cloud)

a) Measurement of the intensity of scattered light by the particles in suspension. The usual angle for measuring the scattered light is at 90 degrees to the incident light. This method of measuring opacity is the most sensitive way of determining the concentration of suspended material in low turbidity treated waters. Instruments incorporating this principle are recommended for use at water

plants, because they are the only ones that measure with great accuracy any water that has a very high clarity. Such instruments are very sensitive and can measure down to 0.03 FTU quite readily, and with great precision. Some plants that periodically have taste and odour problems usually incorporate carbon filters into their treatment system. At such plants, should the treated water become fouled by carbon leakage from a faulty filter,the Nephelometric method cannot be used and a switch to the Absortiometric method becomes necessary in order to measure the carbon particles in suspension.

b) Hach 2100A Turbidimeter (Figure 8-4)
The Hach 2100A Turbidimeter, that has been evaluated by the Ministry of the Environment, uses the Nepholometric principle. This instrument is reliable and performs with great accuracy, if determinations are carried out in the manner described below. This procedure includes several important points not found in the manual issued with the instrument.

c) *Important Points to Remember - in determining Turbidity with the Hach 2100 and Hach 2100A.*

(i) Check that the instrument is optically aligned with the template provided. If alignment is needed, call Technical Advisory Services. On no account should the Plant Technician or Operator try to do the job himself as this necessitates opening the back of the instrument and working near 1800 volts. This is extremely dangerous.

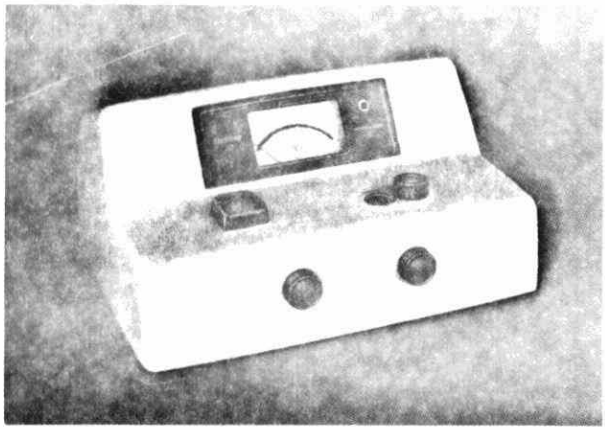


Figure 8-2 SPECTRONIC

Figure 8-3
HELLIGE TURBIDIMETER

Figure 8-4
HACH TURBIDIMETER 2100A

(ii) The temperature of the instrument goes up when the instrument has been recently switched on. This causes the calibration point to slowly drift downward. An operating plateau is reached about 100 minutes after switching on the instrument.

(iii) Always keep the range switch on 0 when using Model 2100 and on 1000 when using Model 2100A, or else the photo sensitive equipment could be damaged.

(iv) Always rotate the range switch in a way that will avoid a lower scale than the sample requires coming into play. If this happens, the indicator needle hits full scale and the instrument goes out of calibration.

(v) Beware of de-gassing samples or covering the cell with greasy fingers.

(vi) Always check the cell, using very low turbidity water to see how clean it really is.

(vii) Standardize the instrument with newly precipitated Formazin Standard Solutions at all ranges. If adjusting is necessary, call Technical Advisory Services.

(viii) Standardize calibration rod against Formazin.

(ix) Never forget to use the cell riser on the 100 and 1000 FTU ranges.

(x) Never leave a sample in the instrument.

(d) Operation Steps

(i) Standardize the instrument with the standards supplied by Hach.

(ii) Check the cell for cleanliness with low turbidity preserved water (supplied by Technical Advisory Services).

(Calibrate as frequently as possible, especially after instrument has recently been switched).

(iii) Fill the clean cell with the carefully stirred sample. Dry and polish the outside with Kimwipes. Place the cell in the instrument and cover it with the light shield.

(iv) Set the range at which the reading is to be made and take a reading.

(v) Return the range to 0 on model 2100 and to 1000 FTU on model 2100A.

(vi) Remove the sample and rinse the cell and replace it in the instrument.

SOLIDS

Total Solids

1. Definition

The total solids of a sample consists of the sum of the weights of the visible solids, which include all the settleable and unsettleable solids, plus the weight of the (invisible) dissolved solids that are in solution.

2. Measurement

a) The only accurate way of measuring the total solids of a sample is by the process of actually weighing a dried sample according to the following method:

b) Apparatus Required:

Porcelain Dishes, Drying Oven, Desiccator, Analytical Balance, and a 50 ml Pipette. (See Figure 8-5).

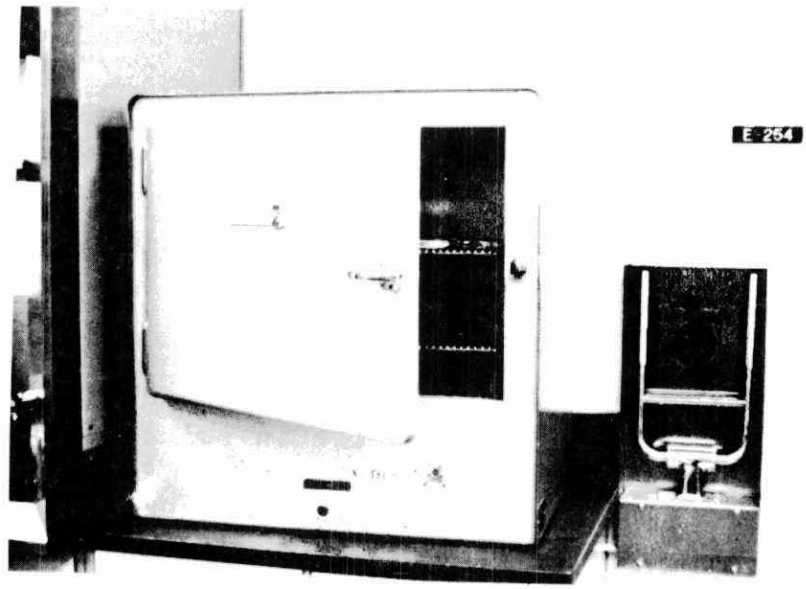


Figure 8-5 Drying Oven

3. Procedure

a) A clean porcelain dish is heated in an oven for two hours at 104°C.

b) It is then cooled in a desiccator for two hours* and weighed on an analytical balance to $\pm$0.0001 gram (W_1).

c) By Pipette, 50 mls of the well shaken sample is placed in it, and it is put to dry in a ventilated oven at 104°C. (This operation is best carried out at the end of the working day, so that the sample can dry undisturbed overnight).

d) The dried sample is then allowed to cool in the desiccator for two hours.*

e) It is then weighed again (W_2) to the same accuracy as before $\pm$0.0001 gram.

f) The total solids calculation is:

(i) $$\frac{W_2 - W_1}{50} \times 1000 \text{ g/l}$$

OR

(ii) $$\frac{W_2 - W_1}{50} \times 1000 \times 1000 \text{ mg/l}$$

* The cooling period is prolonged to 3 or 4 hours if there are several dishes in the desiccator cooling at the same time.

EXAMPLE 50 ml sample portion

Weight Porcelain dish (W_1) = 40,0000 g.

Weight Dish + Dried Residue (W_2) = 40,5403 g.

$$\text{Total Solids} = \frac{W_2 - W_1}{50} \times 1000$$

$$= \frac{40,5403 - 40,0000}{50} \times 1000$$

$$= \frac{,5403}{50} \times 1000$$

$$= 10.806 \text{ g/l}.$$

To convert grams into milligrams multiply by 1000

$\therefore$ Total Solids = 10.806 x 1000

= 10806 mg/l

Suspended Solids

1. Measurement

a) The most accurate method that exists for the direct determination of suspended solids was developed in 1960, when the glass fibre filter first made its appearance on the market. It is known as the Glass Fibre Filter Method.

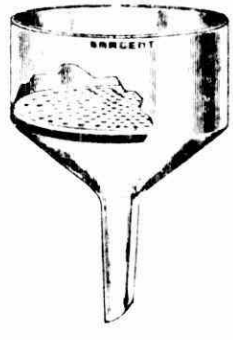
b) The method involves using a glass fibre filter of 0.45 micron pore size, and filtering as large an aliquot as both the size of the sample, and the concentration will allow. Using this method reduces the size of the error that sometimes arises owing to faulty technique, because the factor that is used to calculate the result on the basis of one litre of sample is very much smaller than the factor corresponding to the 50 ml aliquot that is used in the double dish method.

2. Apparatus Required

Glass fibre Filters, a Drying Oven, a Desiccator, an analytical Balance, a 100 ml Pipette, several large Petri Dishes, a Metal Ring (8.5 cm diameter and 4.5 cm deep), a Filter Funnel, a 2 litre Buchner Flask, a Source of Vacuum, and Square Tipped Tweezers. See Figure 8-6.

Petri Dish

Buchner Flask



Filter Funnel

Tweezers

Figure 8-6 Apparatus for Determination of Suspended Solids

3. Procedure

a) Place a glass fibre filter in a funnel that is fitted to a Buchner Flask, which is connected to a source of vacuum.

b) Fill the funnel with distilled water and turn on the vacuum.

c) After about 15 seconds of sucking the filter dry, close the vacuum, and remove the filter with special square tipped tweezers, and place the filter in a clean large Petri dish.

d) Place the Petri dish in the oven and dry the filter for one hour at $104^{o}C$.

e) Place the Petri dish in a desiccator and cool for one hour.

f) Take the filter from the desiccator and weigh it (W_1 grams).

g) Place the filter in the funnel on the buchner flask, and place the metal ring centrally on it.

h) Pipette 100 mls of the sample onto the filter and turn on the vacuum slowly. Keep pipetting onto the filter any amount that the size of the sample and the concentration of the suspended solids in it will allow.

i) When all the sample has passed through the filter, wash the inside of the metal ring onto the filter then wash the filter (to free the dissolved solids in it) twice.

j) Remove the ring from its position on the filter and with the special tweezers take up the filter and place it in the Petri dish.

k) Place the Petri dish in the oven and dry the filter for one hour.

l) Remove the Petri dish containing the dried filter from the oven and place it in the desiccator. Allow it to cool for one hour. (If several filters are taken out of the oven and placed in the desiccator at this time, the cooling period will have to be prolonged).

m) Take the filter from the desiccator and weigh it again (W_2 grams).

n) Calculate the mg/l (ppm) of the suspended solids thus:

$$\frac{W_2 - W_1}{\text{sample aliquot}} \times 1000 = \text{g/l suspended solids}$$

EXAMPLE 100 ml sample portion (aliquot)

$W_1 = 0.4038$

$W_2 = 0.4459$

$$\text{Suspended Solids} = W_2 - W_1 \times 1000 \text{ (g/l)}$$
$$= \frac{0.4459-0.4038}{100} \times 1000$$
$$= \frac{0.0421}{100} \times 1000$$
$$= 0.421 \text{ g/l or } 421 \text{ mg/l (ppm)}$$

Note: g/l x 1000 = mg /l (ppm)

DISSOLVED SOLIDS

The dissolved solids of a sample consist of Calcium and Magnesium soluble salts together with other soluble substances that have been picked up from the terrain through which the water has been flowing.

There are three methods of measurement, *method 3 being the least accurate:*

1. By using the Total Solids method as described previously, except that a filtered sample is used, instead of the sample as received.

2. Mathematically, i.e. subtracting the suspended solids figure as obtained by the glass fibre filter method from the result obtained by the total solids method.

3. Electrometrically, i.e. by measuring the conductance of the sample.

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 9

Electro-Chemical and Titrametric Testing
- pH
- Alkalinity
- Calcium and Magnesium
- Hardness
- Chlorine

OBJECTIVES:

The trainee will be able to carry out and/or describe the methods for determining:

1. The pH of the water by visual or electrometric methods.

2. The hydroxide, carbonate and bicarbonate alkalinity of a given water.

3. The total and calcium hardness.

4. The chloride content in any given water.

ELECTRO-CHEMICAL AND TITRAMETRIC TESTING

pH

pH is a term that is used to express the level or intensity of the acid or alkaline conditions that prevail in a sample. Technically speaking pH is a measure of the hydrogen ion concentration in solution. Theory shows that in aqueous (= water based) solutions this hydrogen ion concentration ranges from a high of 1.0 mole/l down to 0.000 000 000 000 01 mole/l. Since the International System of Atomic Weights established 1 mole of hydrogen to weigh 1 gram this concentration range could be looked upon as 1.0 g/l to 0.000 000 000 000 01 g/l. Figures of this order are not well suited for practical applications and the Danish technician Sorenson suggested a now universally accepted method of expressing the hydrogen ion concentration using logarithms. The above concentrations are nearly always less than 1 mole/l or 1 g/l and the logarithm would nearly always be negative. Sorenson thus used the symbol p in front of the chemical symbol H (for hydrogen) to change the sign of the logarithmic value to positive and called his scale "ph values". For aqueous solutions the scale ranges from 0 to 14 with 7 being the neutral point where a sample is neither acidic, nor alkaline.

Strong Acid				Weak Acid			Neutral Point			Weak Alkali		Strong Alkali		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14

pH Scale

Before discussing methods of pH measurement, it must be emphasized that the pH of a sample is only a measure of the level of acidity or alkalinity in a sample. (i.e. degree of ionization) and not a measure of total acidity or alkalinity. If a decinormal (1/10) Sulphuric acid solution, and a decinormal Acetic acid solution are titrated one at a time, against the same alkali solution, they both have the same neutralizing potential. However, if pH determinations are

made on both of them, the sulphuric acid has a pH of approximately 1, whilst the acetic acid has a pH of about 3. Since the latter has a lower degree of ionization, its pH is higher.

METHODS OF pH MEASUREMENT

There are two methods of pH measurement, visual and electrometric. Visual methods should only be considered when

1. measurement of pH is not too critical, i.e. $\pm$ 0.1 pH error is within the tolerance required.
2. lack of technical knowledge, or practical experience of personnel, prohibits the introduction of electrometric methods in making pH measurements.

VISUAL METHODS

General

There is on the market a large variety of pH indicators for use with comparators or photometers. Dyes (indicators) which change colours at certain pH ranges are added to the sample which has been placed in a Comparator. The colour produced is measured against standard coloured glass discs. It must be noted that pH indicators or indicator papers are effected to various extents by the following sample parameters: dissolved solids, colloids, suspended solids, protein, O.R.P. and solvents. If pH readings accurate to 0.1 pH units are desired, the electrometric method should be used. Errors in determining pH by visual means can result from one or more of the following factors:

1. The human factor, i.e. poor judgment combined with questionable eyesight.
2. Accepting a reading made at either end of the range of the standard disc (only mid-point of the range is used).

3. Waters with low dissolved solids (hence low buffering capacities) do not give the right intensities of developed colour with the indicator.

4. Colour in the water makes matching difficult.

5. Wide variations in sample temperature of the glass standards affects intensity of colour.

6. Inaccurate addition of the recommended quantity of the indicator to the sample. (Quite critical in some cases).

Figure 9-1 LOVIBOND NESSLERIZER

Reagents and Apparatus Required

1. B.D.H. Lovibond Nesslerizer (see Figure 9-1)
2. 2 50 ml Nessler Tubes
3. Discs containing permanent glass colour
4. Standard 0.2 ml Pipettes
5. pH Indicators — pH Range
   a) Bromo Cresol Purple — 5.2 - 6.8
   b) Bromo Thymol Blue — 6.0 - 7.6
   c) Phenol Red — 6.8 - 8.4
   d) Cresol Red — 7.2 - 8.8

Procedure

Select the disc and indicator so that the pH of the sample to be measured falls near the midpoint of its range.

1. Place 50 mls of the sample in each of the two Nessler tubes.
2. Using the tube as a blank put it in the left hand compartment of the Nesslerizer, i.e. the part under the glass standards.
3. Add 0.2 ml of indicator to the other Nessler tube, mix it well and place it in the right hand compartment.
4. Facing the instrument towards a North window, rotate the disc in the hinged lid and take a reading when a colour match is obtained.

Electrometric

1. Principle of Operation
   A measurement is made of the millivoltage that is produced, when a sample and a couple of electrodes of a special type are set up as a galvanic cell. The number of millivolts produced depends on the level of acidity in the cell system.

2. Types of Meters

Several varieties of pH meters are in use. (See Figure 9-2) The basic method for the operation of such instruments is outlined below.

Procedure for Standardizing pH Meter

1. With the switch to the "OFF" position, plug the instrument into an A.C. receptacle of correct voltage. If the instrument is battery operated, check the batteries once monthly (or more often if the instrument is used frequently).
2. Plug the electrodes into the jacks provided.
3. If the electrodes are new, place them in distilled water overnight.

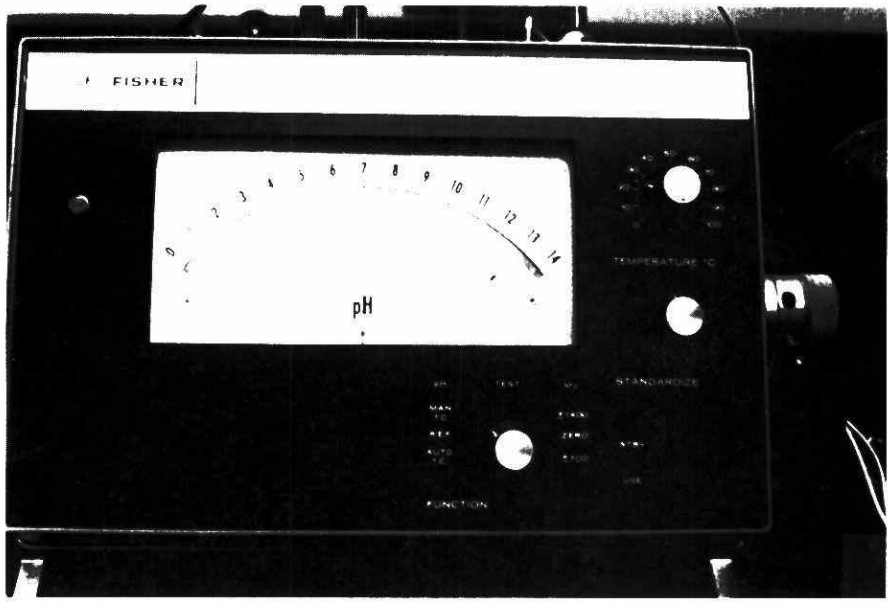
   CAUTION: Support electrodes properly, so they do not come in contact with the beaker (use plastic beakers wherever possible).

4. Turn the instrument to "CHECK" or "STANDBY" position and allow to warm up for 3 to 5 minutes.
5. Carefully remove the electrodes from the beaker they were stored in and rinse them with distilled water.

   NOTE: (a) If the reference electrode is fitted with a rubber plug or sleeve, be certain to expose the filler vent hole to the atmosphere by removing the plug or sliding the sleeve away from the hole.

   (b) A drop of distilled water remaining on the tip of the electrodes does not matter.

6. Fill a separate plastic beaker (100-250 ml volume) with buffer solution, pH 7.00.



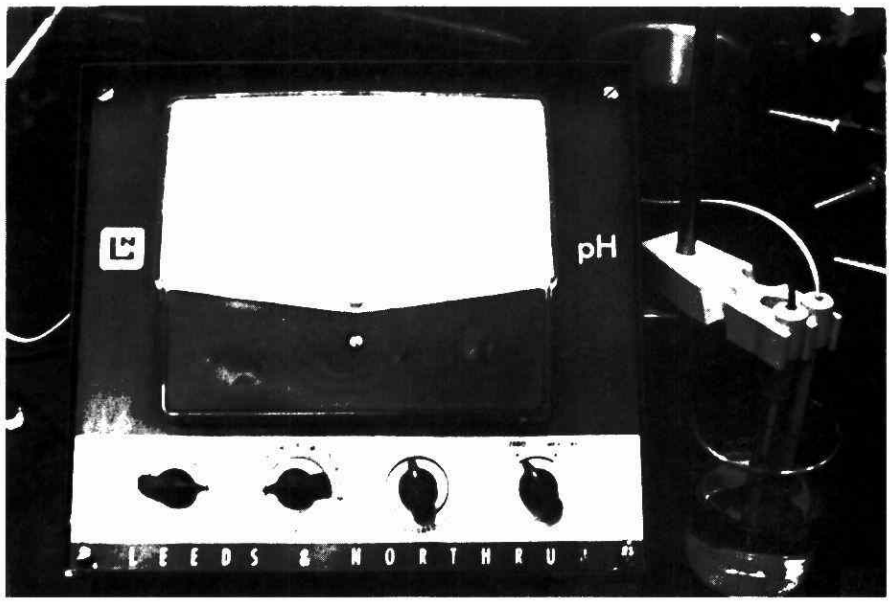


Figure 9-2 pH METERS

7. Measure the temperature of the buffer solution and set the temperature compensator to the temperature of the buffer solution.
8. Immerse the electrodes into the beaker, swirl the beaker carefully without touching the electrodes to the beaker sidewalls.
9. Turn the instrument to "READ" and watch the needle: It should deflect quickly towards the pH value of the buffer solution. The response may slow down when the needle is in within 0.2 pH units from the expected reading, but the needle should give a steady reading after about 30 seconds.
10. If the reading does not correspond with the buffer value, adjust the "STANDARDIZATION" or "BUFFER ADJUST" control to position the needle at the correct buffer value.
11. Turn the instrument back to "STANDBY", remove the electrodes from the buffer solution and rinse them off with distilled water.
12. As a quality check, to assure that the meter and probe respond to pH repeat steps 6, 7, 8 and 9, using a buffer solution of a pH value at least 2 pH units away from the first, a buffer 4.00 solution, for example.

    NOTE: Electrodes tend to respond slower at pH values above pH 7.00, so allow 1 minute before taking a final reading if pH is above 7.00.

13. The second buffer reading should be within 0.2 pH units from the expected value. The meter is now calibrated. Turn the instrument back to "STANDBY".
14. Recalibrate the meter daily.

Taking a Reading

1. Repeat steps 5, 6, 7, 8 and 9, using sample instead of buffer.

   NOTE: The temperature compensator must be adjusted to the temperature of the sample and time allowed for the electrodes to reach the same temperature as the sample; for example, if the buffer temperature is 22°C and the sample temperature only 8°C, allow 3-5 minutes for temperature equalization before taking the final reading.

2. Turn the instrument back to "STANDBY", remove the electrodes from the beaker, rinse them well with distilled water and store them in distilled water. Turn the instrument off if it is no longer used.

   NOTE: Solids adhering to the electrodes from samples such as digester samples should be removable by rinsing. Absorbent tissue such as Kimwipes or Kleenex may be used with caution to remove solids that are not removed by rinsing. DO NOT USE PAPER TOWELS!

GENERAL NOTES ON pH METERS AND ELECTRODES

1. Newer solid state (transitorized) pH meters require less warm-up time than the now outmoded tube-type meters. Tube-type meters are best kept turned on in the "STANDBY" position, unless the manufacturer suggests otherwise.
2. The meters are usually sensitive and should not be jarred, for example, when being transported.
3. Although the better meter types are static-proofed, all meters can be affected by static electricity, especially in dry weather. If the needle seems to

"stick" in a certain position, breathe on the meter face to put a haze on it. If static electricity was "pinning" the needle, it should now become free. Application of an anti-static agent available as liquid or spray in electronics outlets or better record stores will cure this nuisance problem.

4. Electrodes are available as separate glass and reference electrodes or in single assemblies known as combination electrodes. For pH work, both are equally effective, the combination type being more convenient to use since the glass and reference electrodes are packaged into one assembly. Rugged plastic bodied electrodes with protectors for the fragile pH glass bulb are available.

5. The bulb of the glass electrode is constructed of a glass membrane, a few thousandths of an inch in thickness. This makes the bulb extremely fragile and vulnerable. *Scratches on this glass caused by sliding the electrode on the inside wall of a glass beaker can affect pH readings.* When placing the electrode flat on a table, always place the bulb on a soft cloth, sponge, or absorbent tissue.

6. The reference electrodes are normally rugged enough to withstand minor shock and abrasion, but they are also made of relatively thin glass. Keep the electrolyte level high and above the level of the liquid in the beaker. If a pipet or eye-dropper seems inadequate to refill the electrolyte, use a syringe reserved for that purpose. Allowing the electrolyte to dry out can cause permanent electrode failure. A recent development to overcome such problems are sealed gel-filled reference electrodes.

7. After varying periods of usage, the electrodes will become coated with grease from sewage, hardness films from water or final effluents, or caked-on solids from digester samples. NEVER USE HOT WATER TO CLEAN EITHER ELECTRODE. Try immersing the electrodes for a few seconds in a solution having 1 part concentrated hydrochloric acid, and 1 part distilled water to remove film and "caked-on" solids; then rinse well with distilled water. Grease may be removed by wiping the pH electrode bulb with a cloth or tissue soaked with acetone, methyl alcohol or isopropyl alcohol (rubbing alcohol), then rinsing with lukewarm tap water and replacing in the distilled water beaker. Varsol may be used if none of the other cleaning solutions are available.
8. Buffer solutions can be made up according to "Procedures in Standard Methods", but commercially available buffers, either as a dry salt, concentrate, or ready-to-use solution, are preferable when the quantity used is considered. Buffers should be stored in a dark place, such as in the drawer of a laboratory bench or in a BOD incubator. Exposure to bright sunlight or heat causes rapid decomposition of the buffer by accelerating bacterial and algal growth. Buffers are stable *for a few months (not years)* under optimum conditions, and should be purchased or prepared frequently in small amounts. Some commercially-prepared buffer solutions are labelled with an expiry date and should be discarded after this date.
9. The electrical output of a pH electrode is extremely small: about 0.004 microamperes maximum at room temperatures. Touching the plug or getting it wet may be enough to "short circuit" the electrode. For this reason the

contacts on the glass electrode plug should be kept clean by wiping, if necessary, with a clean dry cloth. Tarnished silver contacts should be wiped bright with "Crocus Cloth" or 600 emery or carborundum paper.

10. Failure of the electrodes to produce readings that are within 0.3 to 0.4 of each other in the two buffer standardization techniques previously described, usually signifies defective electrodes.

ANALYSIS BY TITRATION

Whenever two different solutions react completely, without producing hazardous end-products and an indicator can be used to determine when the reaction goes to completion, then they are amenable to an analytical form of measurement that is called Titration.

The solution of known concentration (i.e. standard solution) that is added from a burette is called the *titrant*, and the amount of it in millilitres that is used in a titration is called the *titre*.

When a known volume V_1 of the Standard Solution (S) reacts completely with a known volume V_2 of a solution of an unknown concentration C, then the concentration of the unknown solution can be easily calculated from the following equation:

$$V_1 \times S = V_2 \times C$$

or

$$C = \frac{V_1 \times S}{V_2}$$

ALKALINITY

Causes

The alkalinity of a water refers to its neutralizing capacity (i.e. to its potential as an acid reducer) and its capacity as a buffering agent. In water plants it is often highly desirable to know the types and amounts of the various forms of alkalinity present, in order to carry out efficient softening and coagulation treatment. The levels and types of alkalinity are dependent on the source of the water. Secluded enclosed lakes usually contain less alkalinity than well waters or river waters, especially those rivers that run on limestone rock.

The three major substances causing alkalinity in water, ranked in order of their effect on pH are Hydroxides, Carbonates and Bi-Carbonates. Other substances that contribute to alkalinity to a much lesser extend are Borates, Silicates, Phosphates, and certain salts derived from organic materials. As these substances do not normally occur in amounts where they could become of significant interest in our dealings with natural water, we can neglect taking them into consideration.

Methods of Measurement

The determination of the three types of alkalinity can be achieved by titrating to two different end points, the Phenolphthalein end point (i.e. 8.3 pH) and the Methyl Orange end point (i.e. 4.5 pH). Instead of using indicators the end points may be reached electro-metrically (i.e. using a pH meter) with a resulting increase in accuracy of the method.

Reagents and Apparatus Required (See Figure 9-3)

1. Erlenmeyer flask 250 ml capacity
2. 50 ml Automatic Burette
3. 50 ml Pipette
4. Standard N/50 Sulphuric Acid
5. Indicators - Phenolphthalein and Bromocresol Green - Methyl Red mixed indicator (end point better than Methyl Orange).

Procedure

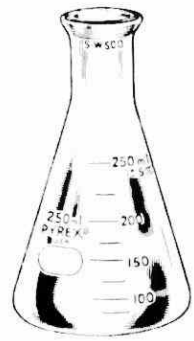
1. Pipette 50 mls of water sample (the aliquot) into 250 ml conical flask.
2. Add 6 drops of Phenolphthalein (P) indicator and swirl to mix.
3. If the colour turns pink, titrate it with standard N/50 Sulphuric Acid that has been placed in the burette. Keep adding acid and swirling until the end point is reached, which is the moment the contents of the flask turns colourless.
4. Record the number of mls used (Titre) T_1. Then the P alkalinity is T_1 x 20 = mg/l as $CaCO_3$. (The factor must be changed if the aliquot is changed).
5. Add one pillow or six drops of the mixed Bromo-cresol Green - Methyl Red Indicator.
6. Continue the titration by adding more Standard N/50 Sulphuric Acid until a second end point is reached. The colour of this end point depends on the pH to be attained, which in turn depends on the range of total alkalinity in the sample.
7. Record the amount of titre (T_2) used (mls). T_2 is the number of mls of acid used in both tests.
8. The TOTAL ALKALINITY is T_2 x 20 = mg/l as $CaCO_3$. (The factor must be adjusted if the aliquot is changed).

Important Points to Remember

The end point of a total alkalinity determination depends on the range of the total alkalinity in the sample.

1. For a range of 30 mg/l, titrate to blue-grey end point, i.e. pH 5.1.
2. For a range of 150 mg/l, titrate to a pinky grey, i.e. pH 4.8.
3. For a range of 500 mg/l, titrate to the first permanent light pink end point, i.e. pH 4.5.

Automatic Burrette



Erlenmeyer Flask

Titration Technique

Figure 9-3 TITRATION

CARBONATE, BICARBONATE AND HYDROXIDE can be expressed individually, by calculating from the following relationships:

Table 9-1 FORMS OF ALKALINITY

	TITRATION RESULTS (mls)	HYDROXIDE	CARBONATE	BICARBONATE
a	$T_1 = 0$	0	0	ALL BICARB
b	$T_1 < 1/2\ T_2$	0	2 x P ALK	TOT ALK-2P.ALK
c	$T_1 = 1/2\ T_2$	0	2 x P ALK	
d	$T_1 > 1/2\ T_2$	2P-TOT ALK	2 (T.ALK-P ALK)	0
e	$T_1 = T_2$	ALL HYDROXIDE	0	0

NOTE: < symbol for "less than"
> symbol for "greater than"

Sample Calculations

EXAMPLE 1

Sample Aliquot = 50 mls.

1. Phenolphthalein Titration

$T_1 = 0.5$ mls

2. Phenolphthalein Alkalinity $= T_1 \times \frac{1000}{\text{aliquot}}$

$= 0.5 \times \frac{1000}{50}$

$= 10$ mg/l

3. Bromo Cresol Green - Methyl Red Titration

$T_2 = 5.1$ mls (this includes the T_1 (0.5 mls) Titration

$\therefore$ Total Alkalinity $= T_2 \times \frac{1000}{\text{aliquot}}$

$= 5.1 \times \frac{1000}{50}$

$= 102$ mg/l

4. To Determine Forms of Alkalinity See Table 9-1

Use formula "b" since $T_1 < 1/2\ T_2$

Hydroxide Alkalinity = 0

Carbonate Alkalinity = 2 Phen Alkalinity
= 2 x 10
= 20 mg/l

Bicarbonate Alkalinity = Total Alk - 2 P. Alk.
= 102 - 20
= 82 mg/l.

EXAMPLE 2

Sample = 100 mls.

1. Phenolphthalein Titration

T_1 = 0 Since no colour development when indicator added.

2. Bromo Cresol Green - Methyl Red Titration

T_2 = 3.8 mls

$$\therefore \text{Total Alkalinity} = T_2 \times \frac{1000}{\text{Sample Portion}}$$

$$= 3.8 \times \frac{1000}{100}$$

$$= 38 \text{ mg/l}$$

3. Forms of Alkalinity

Formula "a" since T_1 = 0

Hydroxide Alkalinity = 0

Carbonate Alkalinity = 0

Bicarbonate Alkalinity = 38 mg/l

HARDNESS MEASUREMENT

A water is considered hard when instead of forming a copious lather with a good soap it just produces a scum. If this happens the cleaning capacity of the soap and water are greatly reduced.

The causes of hardness stem from the presence of Calcium and Magnesium salts in the water. Iron, Aluminium, Manganese and a few other substances also produce hardness, but to such a small degree relative to the Calcium and Magnesium salts, that the latter need not be considered as significant contributors to the level of hardness in water. Thus only total hardness and Calcium hardness are determined.

Ground waters are generally harder than surface waters because the former probably have greater possibilities of picking up Calcium and Magnesium salts by flowing under high pressure through geological strata rich in such salts.

The following scale could be used as a reasonable guide to describe a water in terms of degree of hardness.

0 - 25 mg/l	VERY SOFT
25 - 75 mg/l	SOFT
75 - 150 mg/l	MODERATELY HARD
150 - 300 mg/l	HARD
300 and higher	VERY HARD

TOTAL HARDNESS MEASUREMENT

Apparatus and Reagents Required

1. 50 ml Pipette
2. 250 ml Erlenmeyer Flask (Conical flask)
3. Automatic Burette
4. 0.02N Ethylene Diamine tetra acetic acid
5. Odourless buffer (This buffer is more stable than the Ammonia or Sulphide one.)
6. Eriochrome Black T indicator solution or Manver II powder pillows

Procedure

1. Rinse the pipette and flask with the sample to be used and carefully drain them.
2. Measure 50 mls of the sample into the flask.
3. Add 1 ml of odourless buffer, and swirl to mix.
4. Add 10 drops of Erichrome black T solution or 1 Manver II powder pillow.
5. Titrate the sample with the standard 0.02N EDTA from the burette till the sample colour changes from a wine red to a permanent pure blue.
6. Multiply the mls of titrant (EDTA) used in the titration by 20 (factor for a 50 ml aliquot) to obtain the mg/l total hardness expressed as Calcium Carbonate.

Calculation

Sample Portion (aliquot) = 50 mls

Titrant Used = 8.3 mls

$$\text{Total Hardness} = \text{Titrant Used} \times \frac{1000}{\text{aliquot}}$$

$$= 8.3 \times \frac{1000}{50}$$

$$= 166 \text{ mg/l}$$

Points to Remember

1. The reaction between EDTA, Calcium and Magnesium is not instantaneous, hence the titrant should be added very slowly, when the end point of the titration is approaching. This allows time for reaction and colour changes to take place.
2. If after adding 18-20 mls or more of the EDTA there is no colour change in the sample then either one or a combination of the following reasons might account for the situation.

a) There is possibly too much interference from iron and/or copper.

b) The sample is extremely hard, i.e. more than 400 mg/l total hardness.

c) The required pH for the reaction has not been attained by the addition of 1 ml of the buffer because of the water's initial low pH and high buffering capacity.

3. The solutions to the problems in (2) above are as follows:

a) Add approximately 0.5 gm of Sodium Cyanide to eliminate Iron and Copper interference.

CAUTION: Cyanide is extremely poisonous. Wash your hands carefully before eating. Do not allow the Cyanide to come in contact with acid because Hydrogen Cyanide is evolved and this is a deadly toxic gas.

b) Dilute the sample, taking 100 mls and making it up to 500 mls in a graduated flask with distilled water. Analyze the contents of the flask and multiply the result by the factor of 5 (i.e. after multiplying by the factor of 20 if a 50 ml aliquot was taken from the diluted sample).

c) Add 0.5 to 1.0 ml more Odourless buffer. This amount should take the pH up to the required level.

CALCIUM HARDNESS DETERMINATION

Apparatus and Reagents Required

1. 50 ml Pipette
2. 250 ml Erlenmeyer flask
3. Automatic Burette
4. Indicator Murexide tablets or 1 Calver II powder pillow
5. 0.02N EDTA
6. Buffer 8N Potassium Hydroxide

Procedure

1. Rinse the pipette and flask with the sample and drain them well.
2. Measure 50 mls of the sample into the flask.
3. Add 1 ml of Potassium Hydroxide Buffer and swirl to mix.
4. Then add either 1 Murexide tablet or 1 Calver II powder pillow.
5. Titrate the sample with the standard 0.02N EDTA from the burette, till the sample changes in colour from red to a permanent pure blue.
6. Multiply the mls of titrant used in the titration by 20 (when a 50 ml aliquot is used). The figure then obtained gives the mg/l calcium hardness expressed as Calcium Carbonate.

Points to Remember

1. Magnesium must be present during the titration to obtain a sharp end point. Buffer containing Magnesium complexed with EDTA must be used.
2. The interferences that apply to total hardness also apply to calcium hardness determinations. They can be overcome by the same way.

CHLORIDE CONTENT

General

Chlorides are present in nearly all water sources to a greater or lesser degree depending on the nearness of the source to populated areas, and the geological structures through which the water has passed.

When chloride is combined with calcium and magnesium, and is present in water supplies, the taste threshold at which its presence can be noticed around the range of 900 mg/l concentration. However, when the chloride is combined

with sodium a salty taste becomes detectable around the 250 mg/l concentration; therefore this level has been selected more from the standpoint of taste rather than from any physical hazard that it might present.

Methods of Measurement

The two most prevalent methods for determining chlorides in laboratories conducting water analyses are the Mohr Argentometric method and the Mercuric Nitrate method.

The Mohr method, which has been in use for a long time, has two important drawbacks:

1. The end point colour change from canary yellow to the first permanent appearance of rust red is a more subtle colour change than that which occurs in the mercuric nitrate method. The colour change in the latter method goes from yellow to purple. In the Mohr method, the end point is over shot more often than is generally realized, especially when the test is being done by inexperienced, non-chemically oriented personnel.

   If sulphides or sulphites are present, the colour change is interfered with. This can be overcome by:

   Sulphide present: Add lead nitrate and filter.

   Sulphite present: Add 3 drops 30% hydrogen peroxide.

2. The silver nitrate titrant used in the Mohr method has to be calibrated more frequently than the mercury nitrate titrant, because it decomposes more rapidly than the mercury nitrate.

3. Because of the reasons indicated in sub-paragraph (2)(a) the newer mercury nitrate method is more suitable for plant use, and a description of it now follows.

Chloride Determination by Mercury Nitrate

1. Apparatus and Reagents Required

   a) 25 ml Pipette

   b) 100 ml Erlenmeyer Flask (Conical flask)

   c) Automatic Burette

   d) 0.0141N Mercuric Titrate

   e) Diphenylcarbazone Indicator powder pillows

2. Procedure

   a) Pipette into a 100 ml Erlenmeyer flask (that has been freshly rinsed with distilled water) 25 mls of the sample.

   b) Empty one diphenylcarbazone powder pillow into it and swirl to mix. The sample colour should turn yellow.

   c) Titrate the sample with standard 0.0141N mercury nitrate from the automatic burette until the end point is reached and the colour in the flask goes from yellow to the first permanent purplish tinge.

   d) Take a reading on the burette and multiply the number of mls of mercury nitrate used by 20. (This factor is valid only for a 25 ml aliquot). Factor = 500 divided by mls of sample portion. The result obtained will be in mg/l of chloride present in the sample.

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 10

Colorimetric Analysis

- Selection of Instrument
- Selection of Analytical Method
- Comparison of Analytical Methods

OBJECTIVES:

The trainee will be able to

1. Understand the factors influencing the choice of an analytical method and instrument.

2. Carry out an analysis of water to determine the alunimium, fluoride and iron content.

COLORIMETRIC ANALYSIS

GENERAL

In colorimetric methods, the analyst employs chemical solutions (reagents) which produce specific colours that indicate the presence, and amount of the substance being determined. The intensity of the colours that are formed are compared against coloured standards, and a colour match is made. The standard chosen denotes the concentration of the substance in the sample.

A modification of the above method consists of measuring the intensity of the colour electrically, instead of visually. In this case, an instrument that measures light intensity called a photometer is calibrated with the standard solutions. This is done by measuring the light that passes through each of the standard solutions then doing the same thing to the sample. The standard that absorbs the same amount of light as the sample, denotes the concentration of the substance in the sample.

Colour standards can be made up two ways. They can either be made up synthetically, or they can be made up from the actual substance being determined, by combining it with the reagent to produce the specific colour at the various concentrations.

Various dyes or coloured chemicals are mixed together to form synthetically the colour that is produced when the substance and the reagent react. These colour standards are often quite stable, and dilutions are made from the concentrated synthetic colour solutions to obtain a series of standard.

Actual standards, made from the reaction between the substance being determined and the reagent, usually deteriorate quite rapidly.

In order to measure the colour complex that develops with a specific element, the first requirement is to choose an instrument that gives us the required sensitivity and ease of operation, together with all the other benefits that accrue from good design and low operational costs. The second is to select the most appropriate method that can be used with the instrument in the most effective way to obtain accuracy and precision.

There are numerous methods and instruments for doing the job. Because of this, a brief discussion of the guiding principles that enable one to select the best instruments and chemical methods is in order.

SELECTION OF INSTRUMENT

Two fundamental methods are used for measuring colour intensity:

- The Visual technique
- The Photometric technique.

For good visual measurement the following conditions must be satisfied.

1. Accurate standards for making a successful comparison
2. Absence of initial colour in the water
3. Adequate illumination
4. Even illumination of the two tubes
5. Faultless eyesight
6. Good judgment

For good photometric measurement the following conditions must be satisfied.

1. Instrument functioning properly
2. Accurate calibration

Having taken into consideration the factors that govern both types of instruments, it has to be concluded that the human factor plays an important part in the visual

technique, while it plays no part at all in the other. As a result, an extra possible source of error occurs in the visual technique, and results obtained by the visual method are always suspect. Hence the electrometric (i.e. photometric) techniques can be regarded to be superior to visual techniques, and this includes every type of analytical procedure whether it is colorimetric, pH or turbidity. Figures 10-1 and 10-2 are illustrations of equipment used in photometric determinations.

SELECTION OF AN ANALYTICAL METHOD

The process of selection of a chemical method can become quite involved and time consuming if full consideration is given to each and every factor that governs the performance of the method.

The following is a list of some of the important points that have to be evaluated.

1. Specific for element
2. Obeys Beer's Law (Colour intensity is related to concentration within required analytical range)
3. Stability of the colour complex
4. Interfering substances
5. Reproducibility
6. Sensitivity
7. Independence of temperature
8. Sensitivity to pH
9. Low detection
10. Simplicity and ease of performance
11. Reading time
12. Stability of reagents.

These factors have not been listed in order of their importance, nor do they wield the same influence on the performance of a method.

The majority of the conditions mentioned are self-explanatory; however, the following notes have been written in order to clarify or stress certain aspects of those headings that are not immediately evident in their implications:

1. Low Detection as Compared with Sensitivity

   The limit of detection of the colorimetric method is a function of the reproducibility of the blank (reagent with distilled water). If the blank were perfectly reproducible, the limit of detection would be determined by the smallest change of colour that could be measured on a spectrophotometer. It is quite possible for a reagent to be highly sensitive to an element or radical, but because of its non-reproducible blank, caused by positive or negative interference from other ions, its limit of detection might not be as low as its sensitivity would seem to indicate. This fact is brought out extremely well when we consider that 'N' - Tetramethylbenzidine (in 5% HCl) is twice as sensitive as Orthotolidene, but the limits of detection of the two methods are approximately the same.

2. Reagent Stability

   Several of the reagent solutions used in the methods that are mentioned are only relatively stable. A truly stable reagent is one that can be used until depleted or one that will last indefinitely.

3. Reading Time

   To obtain optimum results, the times selected for reading the colour produced in the sample had to be a compromise between the time the colour has developed fully and the time that interferences from turbidity etc. become significant.

   Table 10-1 compares the most common methods used in water plants. The merits of the various methods depicted in the chart are solely the opinion of its author.

Additionally:-

1. Comments on subjective factors such as convenience and simplicity depend greatly on personal opinion, and circumstance.

2. In some circumstances, the aluminium and iron methods mentioned would tend to give low results if they did not include an initial stage for dissolving colloidal and other complex molecules, particles of these substances.

3. The last point that must always be remembered is that any chemical method is only as good as the analyst using it.

> If he understands what he is doing, does not deviate from the method arbitrarily, and works carefully, then a method that is regarded as "good" is vindicated by the excellent results obtained through its use.

TABLE 10-1 COMPARISON OF ANALYTICAL METHODS

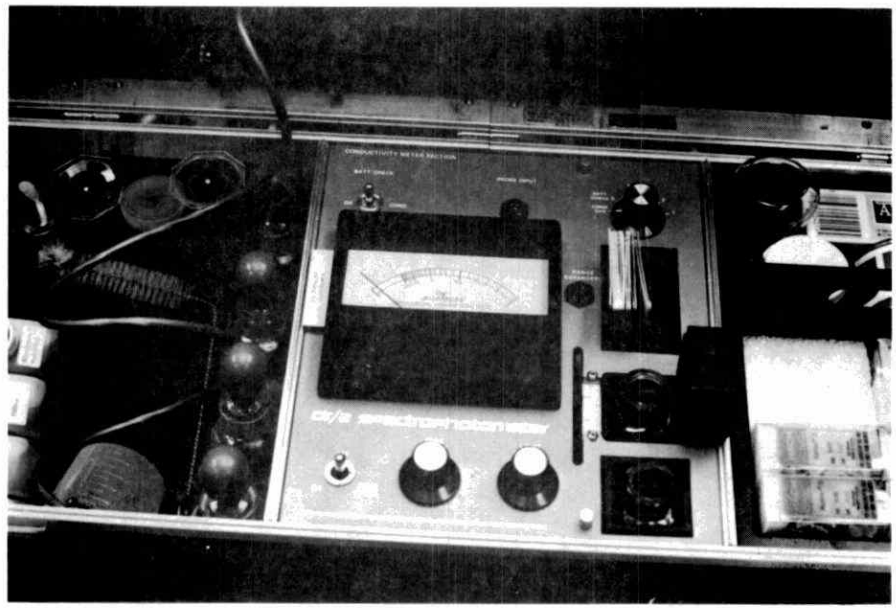
ELEMENTS AND METHODS	REQUIREMENTS	LOW DETECTION	SENSITIVITY	INDEPENDENCE OF TEMP.	REPRODUCIBILITY	STAB. OF REAGENTS	SPECIFICITY	STAB. OF COLOUR	INTERFERENCE	SIMPLICITY	PH SENSITIVE	READING TIME MTS.	CHOICE ORDER
ALUMINIUM METHODS													
AURIN TRICARBOXYLIC	S	P	P	P	P	S	P	P	P	P	30	2	
HAEMATOXYLIN	S	P	P	P	P	P	P	P	P	P	5	3	
ERIOCHROME CYANINE R	S	S	P	S	P	P	P	P	P	P	15	1	
IRON													
THIOGLYCOLLIC	S	S	P	S	P	P	P	P	S	S	5	3	
ORTHO PHENANTHROLINE	S	S	P	S	P	P	S	P	S	P	5	2	
TRIPYRIDYL TRIAZINE	S	S	P	S	P	P	S	P	S	P	1	1	
FLUORIDE													
SPADNS	S	P	U	S	S	P	S	P	S	S	0.1	1	
ALIZARIN ZIRCONYL ACID	P	P	U	P	P	P	P	P	S	S	60	2	

S - CONDITION SATISFIED

P - CONDITION PARTIALLY SATISFIED

U - CONDITION UNSATISFIED

CARRYING CASE
MODEL



LABORATORY MODEL

Figure 10-1 DR/2 SPECTROPHOTOMETER

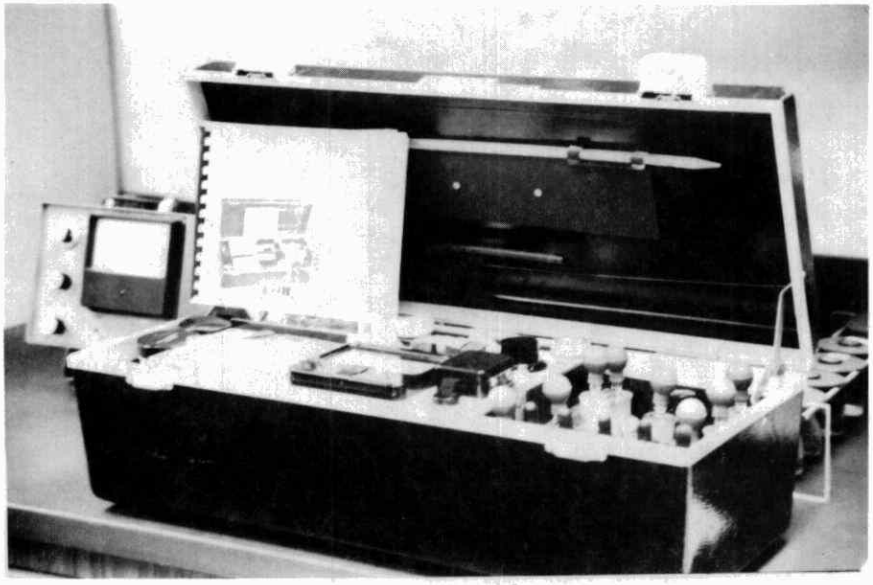


Figure 10-2 Kit Including Photometer, Chemicals and Apparatus

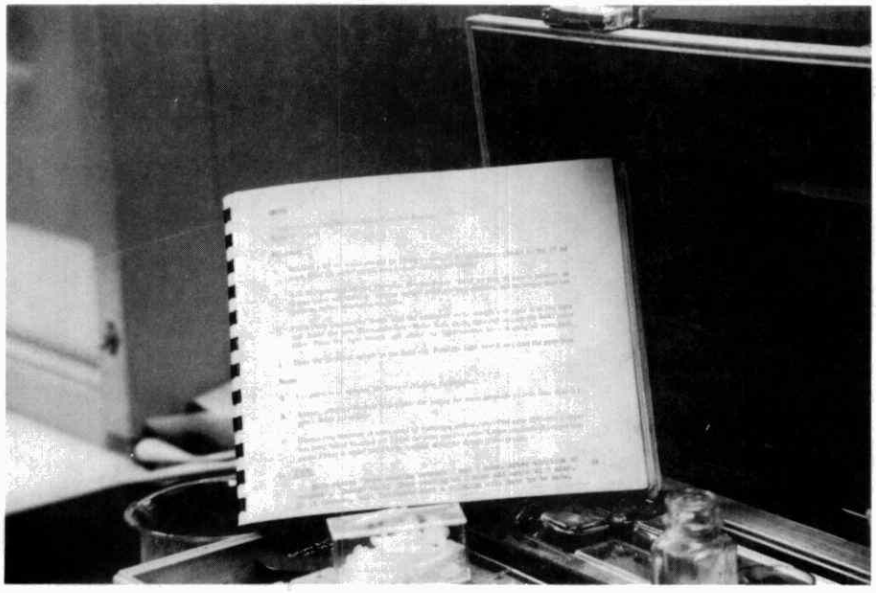


Figure 10-3 Instruction Booklet

Figure 10-4 Adding Chemicals for Analysis

Figure 10-5 Colour Development

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 11

CHLORINE TESTING

OBJECTIVES:

The trainee will be able to

1. Demonstrate and carry out the procedures for determining the chlorine residual using the DPD method with the Nesslerizer and comparator.

2. Determine the chlorine residual of a given sample using the orthotolidene test.

3. Describe the principle of operation of the Amperometric titrator and/or carry out chlorine analysis on such an instrument.

CHLORINE TESTING PROCEDURES

DPD METHOD

Principle of the Method

Research in chlorine chemistry has resulted in the development of a very simple procedure for the determination of its free and total residual. With the new method differentiation between the combined forms of chlorine is also possible using the DPD indicator. The test has a high precision and accuracy and when properly used it can be an excellent aid in the control of chlorine residual at a water treatment plant.

A good feature of the Lovibond Comparator method lies in its use of compressed tablets which are convenient to handle, more stable than the DPD solution, and is a procedure of exceptional simplicity. In a recent investigation by the Water Research Association this method was judged the BEST COLORIMETRIC METHOD for the measurement of chlorine and chloramines in water.

Equipment and Reagents Required

1. DPD tablets for Comparator and Nesslerizer
   a) Nos. 1 & 3 together for total chlorine residual.
   b) No. 1 for free chlorine.
2. Comparator with Standard Lovibond Discs
   a) 3/40A disc covers the range 0.1 to 1.0 mg/l chlorine.
   b) 3/40B disc covers the range 0.2 to 4.0 mg/l chlorine.

   These discs require 13.5 mm. cells or test tubes. A dulling screen must be used.

3. Nesslerizer with Disc

NDP covers the range 0.05 to 0.5 mg/l. This disc must be used with a dulling screen and 50 ml tubes.

Procedure

1. Compactor

a) Determining Total Chlorine Residual

(i) Place a 13.5 mm cell or test tube containing sample only in the lefthand compartment, behind the colour standards of the disc.

(ii) Rinse a similar cell with the sample, and fill the cell or tube up to the mark with it.

(iii) Into this cell or tube drop one No. 1 and one No. 3 tablet (or one No. 4 tablet, which is No. 1 and No. 3 combined.

(iv) Allow tablets (or tablet) to disintegrate until effervescence ceases.

(v) *Mix rapidly* to dissolve the remains of the tablet.

(vi) Place the cell in the righthand compartment of the Comparator.

(vii) *After 2 minutes*, match the cells by holding the Comparator facing a good source of diffused north daylight and *revolve this disc until the correct standard is found. NEVER LOOK INTO THE SUN.*

(viii) The figure shown in the indicator window represents mg/l of *total chlorine residual* present in the sample.

b) Determining of Free Chlorine Residual

(i) Prepare tubes as outlined above for total chlorine residual, one "blank" tube and one with just a few drops of sample.

(ii) To the tube with sample, add one No. 1 tablet only.

(iii) After disintegration, add water up to mark, and

(iv) Mix as before and match at once. This gives *free chlorine residual.*

Note: It is permissible to determine TOTAL CHLORINE on the same sample by continuing as follows: add one No. 3 tablet, mix and stand for 2 minutes. The colour then read off represents *total chlorine residual.*

c) Determining Combined Chlorine Residual

Total Chlorine Residual - Free Chlorine Residual = Combined Chlorine Residual Value.

2. Nesslerizer

Follow exactly the same procedure for the Comparator, with the following exceptions:

a) Use 50 ml instead of 10 ml.

b) Use special Nesslerizer DPD tablets.

Note: *It must be emphasized that the readings obtained by means of the B.D.H. Lovibond Nesslerizer and disc are only accurate provided that Nesslerizer glass is used which conforms to the specification employed when the discs are calibrated, namely, that the 50 ml calibration mark shall fall at a height of 113 ± 3 mm, measured internally.*

3. False Colour due to Interferences

a) The only interfering substance likely to be present in water is oxidized manganese from potassium permanganate in those water plants that use it for taste and odour control.

b) Test the unchlorinated water for colour development and use as a Blank.

c) *All glassware used must be very thoroughly rinsed after making a test, since only a trace of potassium iodide will cause chloramine colour to develop. Handling the tablets should be avoided. By shaking one tablet into the bottle top it is a simple matter to use the top for conveying the tablet to the Comparator cell or Nessler tube.*

ORTHOTOLIDENE TEST (OT)

General

The orthotolidene test (OT) is used to determine the presence of chlorine residuals in the water. The water is tested for total chlorine residual 15 minutes or longer after chlorination by adding the sample to the OT reagent in a glass tube or glass container. A yellow colour in the sample indicates the presence of a chlorine residual. The deeper the yellow the greater the residual. A lemon yellow colour indicates a safe residual for drinking water.

An approximate free chlorine residual can be determined only when the temperature of the sample is at or very near freezing. The colour caused by free chlorine residuals develops instantly at water temperatures near freezing after the OT reagent is added to the sample. Colour caused by the combined residual develops more slowly, and normally takes up to 5 minutes. The speed of colour development of combined residuals is increased with higher water temperatures.

It is possible that in highly alkaline waters (quite rare in Ontario) a blue tinge may result instead of the yellow colour. This may be corrected by adding an excess amount of OT reagent. Since the reagent is acidic, it will neutralize the excess alkalinity in the water sample. It should be noted that adding too much OT reagent introduces inaccuracies in the residual reading.

The OT method is an old one dating back to 1914, and is still in use in many plants. It has two disadvantages:

1. The super-sensitivity of the chemical causes high intensity colour development so that a chlorine residual cannot be measured accurately above 1 ppm concentration.
2. Free chlorine residual determination only gives an approximate result; ie. you get an idea of its range. The OT method must not be used when an accurate free chlorine residual is required.

To add to this, iron, manganese and nitrites can cause a false colour. The OT method is slowly being replaced by the DPD and the Amperometric methods both of which will be discussed in this workshop.

Procedure for Total Chlorine Residual

1. Pour the required amount of OT reagent into the Nessler tube, Colorimeter cell or other container. Use
   - 0.5 ml OT reagent in 10 ml cell
   - 0.75 ml OT reagent in 15 ml cell
   - 5.0 ml OT reagent in 100 ml cell

   and similar ratios for other volumes.

   Note: *OT reagent should not be kept longer than 6 months. It should be stored in amber-coloured bottles, kept out of direct sunlight and should not be subjected to high or low temperature. Fresh supplies of OT reagent may be obtained free of charge from the M.O.E. Laboratories.*

2. Adjust the temperature of sample to between 15°C and 24°C (quickly) using warm or cold water.

3. Add sample to the cell or tube up to the mark.

4. Mix solution.

5. About 5 minutes after maximum colour develops, a slight fading begins; therefore, samples containing combined chlorine should be read within 5 minutes and should, preferably, be allowed to develop colour in the dark.

Free Chlorine Residual Test

1. An orthotolidene *flash test* modification for free chlorine residual performed near 1°C (34°F) or freezing point minimizes the effect of chloramines and their reaction with orthotolidene to produce a yellow colour. Temperature is a critical factor. The sample should be near the freezing point to obtain meaningful results. This is in direct contrast to the OT procedure for combined chlorine residual where the temperature of the sample should be around 20°C (68°F).

2. Although oxidized manganese affects the test results, slow-acting interfering substances, nitrites and oxidized iron, do not have a significant influence. The flash test has the disadvantage of requiring the *reading of colour within 5 minutes*.

3. *This method is suitable for estimating only.*

4. Procedure for Flash Test

   a) Cool the sample quickly to within one degree of the freezing point.

   b) Add the appropriate amount of orthotolidene reagent that is adequate for the cell or Nessler tube.

   c) Fill the cell or tube up to the mark with the sample.

   d) Place it in the comparator or Nesslerizer and read immediately.

AMPEROMETRIC TITRATION METHOD

General

The most accurate methods of measuring free and combined chlorine residuals is through oxidation-reduction titration procedures. Such methods require the use of internal indicators or electrometric devices employing a suitable electrode system to show when reactions are completed. Amperometric titrators employing rotating platinum electrodes have been developed for such purposes. See Figure 11-1, page 11-11.

Phenylarsene oxide is the reducing agent normally used as the titrating agent. It reacts with free chlorine residuals at pH 6.5 to 7.5 in a quantitative manner.

By conducting a two-stage titration, with the pH adjusted at about 7 and then at about 4, it is possible to measure separately free chlorine residuals and combined chlorine residuals.

Titrator - Principle of Operation

Titration is a method used to determine the concentration of a substance in a solution. This is accomplished by adding the smallest amount of a reagent (of known concentration) required to cause a neutralizing effect, in reaction with a known volume of the test solution. A graduated vessel (or burette) is used to add the reagent to the known volume of test solution until the chemical reaction between the two is completed. The point of completion is indicated by either (a) adding an indicator dye and watching for a change in its odour or (b) stopping at a predetermined end point on a pH meter or microammeter.

A direct current potential is impressed across two nodal metal electrodes immersed in a measuring cell containing the sample of the solution to be tested. Any

flow of current between the electrodes is directly proportional to the quantity of halogen (such as chlorine, bromine, or iodine) in the sample. The presence of a current is indicated on a microammeter at the top of the instrument.

A reagent (also called a titrant) is added in small doses to the sample, and reacts chemically with the chlorine present in the solution, thereby neutralizing a portion of the chlorine. As more titrant is added, more chlorine is "removed", causing the current flowing between the electrodes to diminish as indicated by the microammeter pointer moving down the scale. Finally, sufficient titrant is added to react with all the chlorine, and no further decrease in current is possible. This is called the *end point*.

The amount of chlorine residual present in the test solution is determined by noting the number of millilitres of titrant used to attain the end point. Then:

mg/l of chlorine = mls of titrant that have been used.

Procedure

1. Filling the Burette
   Make sure the titrant (phenylarsene oxide solution) fills to the zero mark.

2. Titration of Free Chlorine Residual

   a) Fill the solution jar with 200 ml of sample.

   b) Add 1 ml pH 7 buffer solution.

   c) Fill the microburette with the titrant (phenylarsene oxide solution) to the zero mark.

   d) Titrate by adding phenylarsene oxide solution and observe current changes on the microammeter. As long as addition of phenylarsene oxide produces a definite decrease in current, free chlorine residual is present.

e) The end point is just passed when a very small increment of phenylarsene oxide no longer causes a decrease in current.

f) The burette is then read and the last increment of titrating solution is subtracted from the reading to give a value representing the free chlorine residual.

3. Titration of Total Chlorine Residual

a) To the sample remaining from the free chlorine titration add 1 ml potassium iodide solution and then 1 ml pH 4 buffer solution IN THAT ORDER.

b) Titrate with phenylarsene oxide solution to an end point, just as above for the free chlorine residual. It is most convenient NOT to refill the burette but simply to continue the titration.

c) After concluding the titration and having found the end point, subtraction of the last increment again gives the amount of titrating solution actually used in reaction with the chlorine.

d) If the titration was continued without refilling the burette, this figure represents the total chlorine residual. Substracting the free chlorine residual from the total gives the combined chlorine residual, or

Total Chlorine Residual - Free Chlorine Residual = Combined Chlorine Residual

Note: *It is essential to wash the apparatus and sample cell thoroughly to remove iodide ion and acetate buffer after this determination, in order to avoid inaccuracies if the titrator is subsequently used for free available chlorine determination.*

e) If desired, the determination of the total chlorine residual and the free chlorine residual may be made on separate samples. If only the value for total chlorine residual is required, it is permissible to treat the sample immediately with 1 ml potassium iodide solution followed by 1 ml pH 4 buffer solution. The titration is carried out with phenylarsene oxide solution as described on page 11-3 (2(c)).

Monochloramine and Dichloramine Differentiations

It is often desirable to differentiate between the monochloramine and dichloramine portion of the combined chlorine residual in a sample solution. This differentiation is accomplished in the following manner:

1. Perform the procedure outlined in Procedure for for the Titration of Free Chlorine Residual. Note the reading in ppm (free chlorine).
2. Add 4 to 5 drops of potassium iodide, 5% solution to the sample jar. If monochloramine is present, the ammeter pointer will deflect to the right.
3. Titrate to the "end point"; note the reading in ppm.
4. Add 1 dropper of pH 4 buffer solution and add 1 dropper of potassium iodide, 5% solution to the sample jar. If dichloramine is present, the ammeter pointer will again deflect to the right.
5. Titrate to the "end point"; note the reading in ppm.

The difference between the readings obtained in step 1 ("free" chlorine) and step 3 preceding, represents the monochloramine component.

The difference between the readings obtained in step 3 and step 5 represents the dichloramine component.

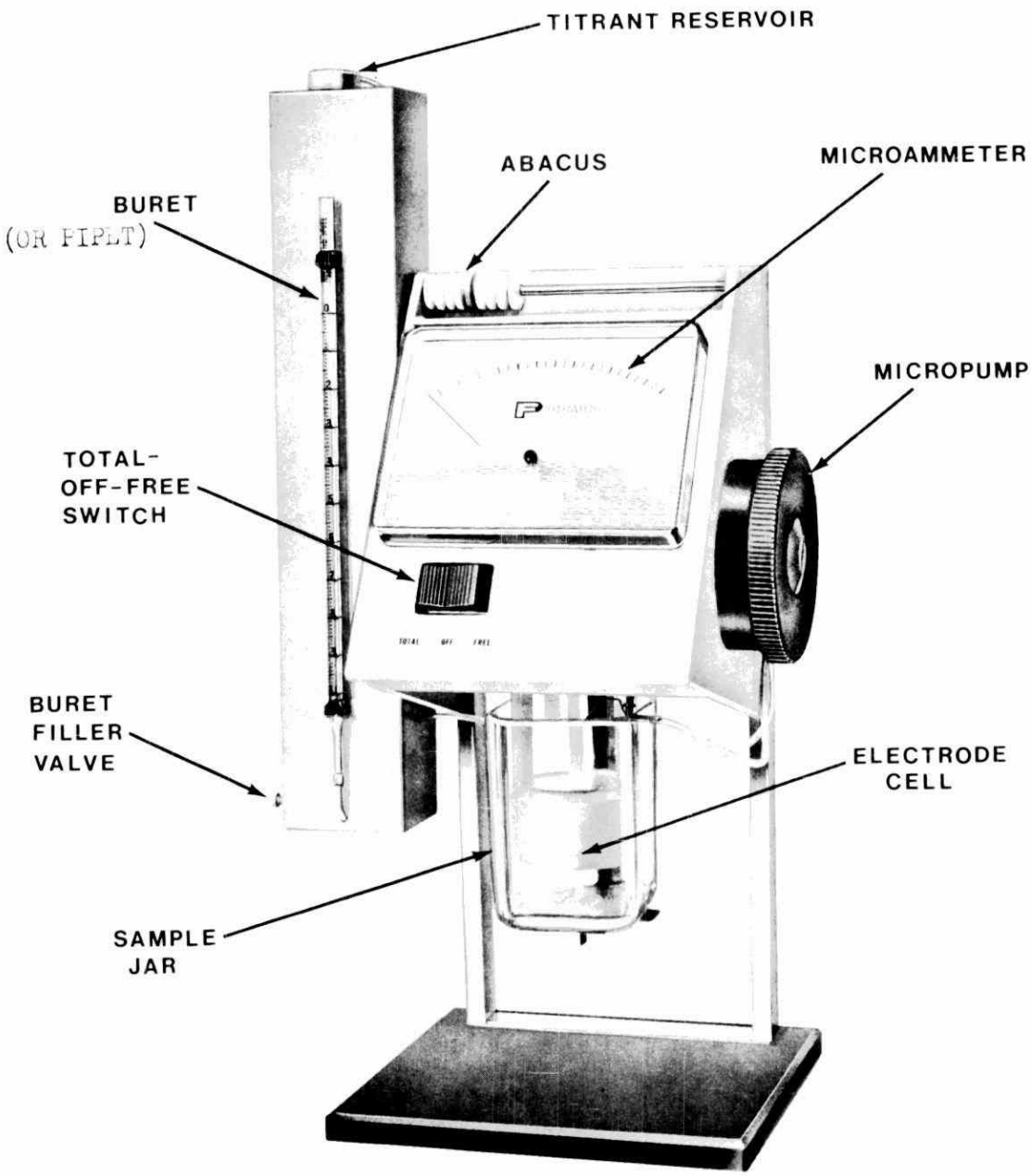


Fig. 11-1 Amperometric Titrator
(Courtesy Fischer & Porter)

SUBJECT:

SURFACE WATER TREATMENT

TOPIC: 12

Corrosion

OBJECTIVES:

The trainee will understand the application of the Langelier Index to determine whether water of a known pH is scale forming or corrosive.

CORROSION

GENERAL

Corrosion is a complex subject which cannot be treated comprehensively in the time and space available. This manual discusses in some detail how to obtain the best quality water prior to discharge to the distribution system. This topic briefly discusses how to keep this top quality water from becoming a low grade product due to corrosion.

A seriously corroded distribution system can give rise to foul-tasting water with the presence of smelly sulphides, "rotten" organic flavours, as well as precipitated iron. In some systems, metals such as copper or lead can reach toxic levels.

Very often such corrosion problems lead to constant flushing of mains and taps by civic employees and consumers respectively. This can result in a significant expense to the community.

THE CONCEPT OF CORROSION

A "corrosion-free" system develops when an adherent, highly insoluble coating forms on the pipeline surface. Exposed surfaces are usually stabilized by the corrosion process. If the normal process is interfered with, unchecked corrosion may result. There are several possibilities why this may occur:

1. Component materials or impurities may be lacking in the alloy or water to form a suitably resistant surface compound.
2. The water may contain compounds which are so aggressive that they may dissolve the previously insoluble protective coatings.
3. Coatings that were initially insoluble may decompose upon changes in the water environment and release previously compounded metal ions.

Causes of such coating solubilization, however, may be the result of electrolysis, biological growths, or general chemical aggressiveness. Electrolysis involves the local effects of grounded electrical apparatus in the neighbourhood and normally corrodes the outside of watermains at a faster rate. Bacterial growths can arise particularly where the water is relatively high in organic contaminants. Taste and odour problems tend to predominate. Chemically agressive waters have generally very low solids, low hardness or low pH. A common and useful scale for linking all of these factors is the Langlier Index, reproduced on Page 12-3.

LANGELIER INDEX

The Langelier Index plays an important role in judging the chemical aggressiveness of the water. Most water supplies in Ontario contain the component ions of calcium and carbonate. Using Table 12-1, one can calculate the pH at which the calcium carbonate saturation approaches a positive value. Once this positive value is obtained, an impermeable film of this material will normally coat corrodible surfaces protecting them from attack.

Chemicals commonly used in Ontario to obtain such a pH include lime, sodium carbonate and soda ash. This is discussed in more depth in the Water Treatment Chemicals Section.

The Langelier Index is only a guide and any water plant wishing to obtain the optimum pH to prevent corrosion should first contact the nearest Ministry of the Environment Regional Office.

Sample Problem

A water had the following characteristics:

Calcium hardness - 50 mg/l as $CaCO_3$
Alkalinity - 35 mg/l as $CaCO_3$
Total Solids - 100 mg/l
Temperature - $50^{o}F$

PERMUTIT

TABLE 12-1

SECTION 76. $CaCO_3$ SATURATION INDEX (LANGELIER INDEX)

(Based on the Langelier Formula: Larson—Buswell: Residue—Temperature Adjustments: Arranged by Nordell)

1. $pH_s = (9.30 + A + B) - (C + D)$
   (NOTE. Values of A, B, C & D are obtained from tables A, B, C & D)
2. Saturation Index $= pH - pH_s$

   If index is 0, water is in chemical balance.

   If index is a plus quantity, scale forming tendencies are indicated.

   If index is a minus quantity, corrosive tendencies are indicated.

Example: To find the saturation index at 124° F. of water which has the following characteristics: Total solids—400 ppm; calcium hardness as $CaCO_3$—240 ppm; alkalinity as $CaCO_3$—196 ppm; and pH of 7.2. Then:

Total solids ..... 400 ppm = 0.16 (from table A)
Temperature ..... 124° F. = 1.53 (from table B)
Calcium hardness as $CaCO_3$ ..... 240 ppm = 1.98 (from lower table C)
Alkalinity as $CaCO_3$ ..... 196 ppm = 2.29 (from upper table D)

Substituting: $pH_s = (9.30 + 0.16 + 1.53) - (1.98 + 2.29) = 6.72$ (or 6.7)
Saturation Index $= 7.2 - 6.7 = +0.5$

A

Total Solids in ppm

Ppm Total Solids	
50	.07
75	.08
100	.10
150	.11
200	.13
300	.14
400	.16
600	.18
800	.19
1000	.20

B

Temperatures in degrees Fahrenheit

TENS \ UNITS	0	2	4	6	8
30		2.60	2.57	2.54	2.51
40	2.48	2.45	2.43	2.40	2.37
50	2.34	2.31	2.28	2.25	2.22
60	2.20	2.17	2.14	2.11	2.09
70	2.06	2.04	2.03	2.00	1.97
80	1.95	1.92	1.90	1.88	1.86
90	1.84	1.82	1.80	1.78	1.76
100	1.74	1.72	1.71	1.69	1.67
110	1.65	1.64	1.62	1.60	1.58
120	1.57	1.55	1.53	1.51	1.50
130	1.48	1.46	1.44	1.43	1.41
140	1.40	1.38	1.37	1.35	1.34
150	1.32	1.31	1.29	1.28	1.27
160	1.26	1.24	1.23	1.22	1.21
170	1.19	1.18	1.17	1.16	

C

Calcium hardness expressed as ppm $CaCO_3$
(For 3 to 209 ppm $CaCO_3$, use upper table)
(For 210 to 990 ppm $CaCO_3$, use lower table)

TENS \ UNITS	0	1	2	3	4	5	6	7	8	9
0				0.08	0.20	0.30	0.38	0.45	0.51	0.56
10	0.60	0.64	0.68	0.72	0.75	0.78	0.81	0.83	0.86	0.88
20	0.90	0.92	0.94	0.96	0.98	1.00	1.02	1.03	1.05	1.06
30	1.08	1.09	1.11	1.12	1.13	1.15	1.16	1.17	1.18	1.19
40	1.20	1.21	1.23	1.24	1.25	1.26	1.26	1.27	1.28	1.29
50	1.30	1.31	1.32	1.33	1.34	1.34	1.35	1.36	1.37	1.37
60	1.38	1.39	1.39	1.40	1.41	1.42	1.42	1.43	1.43	1.44
70	1.45	1.45	1.46	1.47	1.47	1.48	1.48	1.49	1.49	1.50
80	1.51	1.51	1.52	1.52	1.53	1.53	1.54	1.54	1.55	1.55
90	1.56	1.56	1.57	1.57	1.58	1.58	1.58	1.59	1.59	1.60
100	1.60	1.61	1.61	1.61	1.62	1.62	1.63	1.63	1.64	1.64
110	1.64	1.65	1.65	1.66	1.66	1.66	1.67	1.67	1.67	1.68
120	1.68	1.68	1.69	1.69	1.70	1.70	1.70	1.71	1.71	1.71
130	1.72	1.72	1.72	1.73	1.73	1.73	1.74	1.74	1.74	1.75
140	1.75	1.75	1.75	1.76	1.76	1.76	1.77	1.77	1.77	1.78
150	1.78	1.78	1.78	1.79	1.79	1.79	1.80	1.80	1.80	1.80
160	1.81	1.81	1.81	1.81	1.82	1.82	1.82	1.82	1.83	1.83
170	1.83	1.84	1.84	1.84	1.84	1.85	1.85	1.85	1.85	1.85
180	1.86	1.86	1.86	1.86	1.87	1.87	1.87	1.87	1.88	1.88
190	1.88	1.88	1.89	1.89	1.89	1.89	1.89	1.90	1.90	1.90
200	1.90	1.91	1.91	1.91	1.91	1.91	1.92	1.92	1.92	1.92

HUNDREDS \ TENS	0	10	20	30	40	50	60	70	80	90
200		1.92	1.94	1.96	1.98	2.00	2.02	2.03	2.05	2.06
300	2.08	2.09	2.11	2.12	2.13	2.15	2.16	2.17	2.18	2.19
400	2.20	2.21	2.23	2.24	2.25	2.26	2.26	2.27	2.28	2.29
500	2.30	2.31	2.32	2.33	2.34	2.34	2.35	2.36	2.37	2.37
600	2.38	2.39	2.39	2.40	2.41	2.42	2.42	2.43	2.43	2.44
700	2.45	2.45	2.46	2.47	2.47	2.48	2.48	2.49	2.49	2.50
800	2.51	2.51	2.52	2.52	2.53	2.53	2.54	2.54	2.55	2.55
900	2.56	2.56	2.57	2.57	2.58	2.58	2.58	2.59	2.59	2.60

D

Alkalinity expressed as ppm $CaCO_3$
(For 1 to 209 ppm $CaCO_3$, use upper table)
(For 210 to 990 ppm $CaCO_3$, use lower table)

TENS \ UNITS	0	1	2	3	4	5	6	7	8	9
0		0.00	0.30	0.48	0.60	0.70	0.78	0.85	0.90	0.95
10	1.00	1.04	1.08	1.11	1.15	1.18	1.20	1.23	1.26	1.29
20	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.43	1.45	1.46
30	1.48	1.49	1.51	1.52	1.53	1.54	1.56	1.57	1.58	1.59
40	1.60	1.61	1.62	1.63	1.64	1.65	1.66	1.67	1.68	1.69
50	1.70	1.71	1.72	1.72	1.73	1.74	1.75	1.76	1.76	1.77
60	1.78	1.79	1.79	1.80	1.81	1.81	1.82	1.83	1.83	1.84
70	1.85	1.85	1.86	1.86	1.87	1.88	1.88	1.89	1.89	1.90
80	1.90	1.91	1.91	1.92	1.92	1.93	1.93	1.94	1.94	1.95
90	1.95	1.96	1.96	1.97	1.97	1.98	1.98	1.99	1.99	2.00
100	2.00	2.00	2.01	2.01	2.02	2.02	2.03	2.03	2.03	2.04
110	2.04	2.05	2.05	2.05	2.06	2.06	2.06	2.07	2.07	2.08
120	2.08	2.08	2.09	2.09	2.09	2.10	2.10	2.10	2.11	2.11
130	2.11	2.12	2.12	2.12	2.13	2.13	2.13	2.14	2.14	2.14
140	2.15	2.15	2.15	2.16	2.16	2.16	2.16	2.17	2.17	2.17
150	2.18	2.18	2.18	2.18	2.19	2.19	2.19	2.20	2.20	2.20
160	2.20	2.21	2.21	2.21	2.21	2.22	2.22	2.23	2.23	2.23
170	2.23	2.23	2.23	2.24	2.24	2.24	2.24	2.25	2.25	2.25
180	2.26	2.26	2.26	2.26	2.26	2.27	2.27	2.27	2.27	2.28
190	2.28	2.28	2.28	2.29	2.29	2.29	2.29	2.29	2.30	2.30
200	2.30	2.30	2.30	2.31	2.31	2.31	2.31	2.32	2.32	2.32

HUNDREDS \ TENS	0	10	20	30	40	50	60	70	80	90
200		2.32	2.34	2.36	2.38	2.40	2.42	2.43	2.45	2.46
300	2.48	2.49	2.51	2.52	2.53	2.54	2.56	2.57	2.58	2.59
400	2.60	2.61	2.62	2.63	2.64	2.65	2.66	2.67	2.68	2.69
500	2.70	2.71	2.72	2.72	2.73	2.74	2.75	2.76	2.76	2.77
600	2.78	2.79	2.79	2.80	2.81	2.81	2.82	2.83	2.83	2.84
700	2.85	2.85	2.86	2.86	2.87	2.88	2.88	2.89	2.89	2.90
800	2.90	2.91	2.91	2.92	2.92	2.93	2.93	2.94	2.94	2.95
900	2.95	2.96	2.96	2.97	2.97	2.98	2.98	2.99	2.99	3.00

1. At what pH would the water be neither scale-forming nor corrosive?

2. If this water had a pH of 5.8 units, determine how much sodium carbonate would be required to obtain a corrosive-free water.

3. Assuming the operator added 50 mg/l of sodium carbonate and obtained a pH of 8.5, is this water corrosive or scale-forming?

SUBJECT:

TOPIC: 13

Jar Tests

PROCESS CONTROL TESTS

OBJECTIVES:

The trainee will be able to:

1. Recall the purpose of jar tests;
2. Prepare stock chemical solution;
3. Demonstrate the procedure for carrying out a jar test;

JAR TESTS

PURPOSE

Jar tests are used to determine the correct amount of coagulant.

The following chart indicates the advantages of using the proper dosage of alum solution as a coagulant:

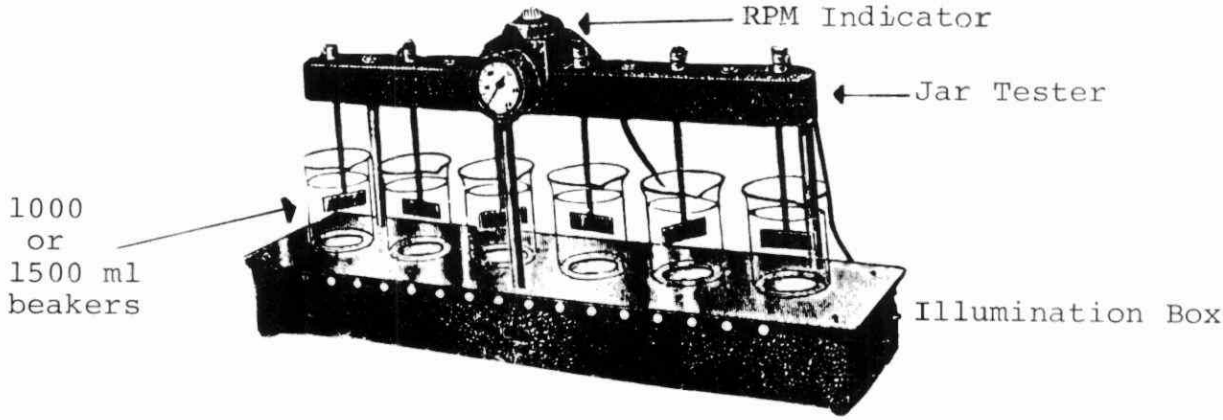
	Under Dose	Proper Dose	Over Dose
Turbidity removal	Poor	Good	Fair
Colour removal	Poor	Good	Fair
Algae removal	Poor	Good	Fair
Length of filter runs	Medium	Long	Short
Residual aluminum	High	Low	High
Dollar value	Wasted	Good	Poor

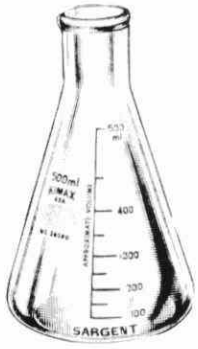
EQUIPMENT REQUIRED (See illustrations on page 13-2)

1. Jar Tester (4 or 6 paddles)
2. Illuminator Box (preferred but not essential)
3. Beakers - 6 (100 or 1500 ml capacity)
4. Pipettes - 5 1-ml graduated (glass)
5. Erlenmeyer Flasks - 6 250-ml capacity
6. Funnels - 6 ribbed, conical 2.5 inch diameter, short stemmed
7. Graduated Cylinders - 2 100-ml (plastic or glass)
   1 1000-ml (plastic or glass)
8. Filter Paper - 11 cm. S&S Black Ribbon 589, or Whatman #41
9. Baster
10. Scale - accurate to 1/20 of a gram
11. Bacteriological sampling bottles - no preservative.

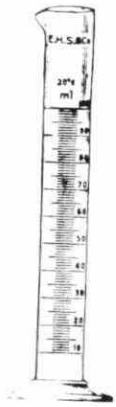
JAR TEST EQUIPMENT

Figure 7



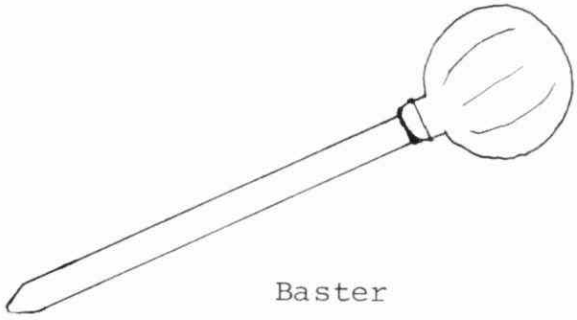


Erlenmeyer Flask



Graduated
Cylinder

Conical Ribbed
Funnel



Baster

Figure 13-1 Jar Test Equipment

TREATABILITY TEST SHEETS

An example of a helpful guide for carrying out the jar test is illustrated in Table 13-1. Your raw water analysis should be carried out and entered in the Raw Water Analysis Section (upper left corner). With this analysis complete, the operator is ready to carry out the various jar test steps.

CHEMICAL SOLUTIONS

Stock solutions of coagulants, coagulant aids and other chemicals should be prepared at concentrations such that quantities suitable for use in coagulation tests can be measured accurately and conveniently.

Chemical	Concentration of Stock Sol.	Prepare Fresh Solution After	1 ml in 1000 ml of H_2O Equiv. to
Alum	1%	1 month	10 mg/l
Ferric Chloride	1%	2 months	10 mg/l
Activated Silica	1%	2 days	10 mg/l
Polyelectrolyte	0.05%	1 week	0.5 mg/l
Sulphuric Acid	0.1N	3 months	4.9 mg/l

NOTES:

- Alum - 1% solution can be made by adding 1 g of powdered alum to 100 mls of water OR 1.54 mls of liquid alum to 100 mls of water.

- Activated Silica solutions necessary for the preparation of a 1% solution can be obtained through your Ministry of the Environment regional engineer.

- Polyelectrolyte solutions should be used with the guidance of the manufacturers.

TURBIDITY	J.T.U.
COLOUR	HAZEN
pH	
FLOC TEMPERATURE	
ALKALINITY	MG/L
HARDNESS	MG/L
IRON	MG/L
CHLORINE	MG/L

DATE

LOCATION

RAW WATER ANALYSIS
RUN NO.

SOURCE

CHEMICALS					pH		FLOC			SUPER-NATANT	FILTERED SUPERNATANT ANALYSIS							
JAR #	MG/L	MG/L	MG/L	MG/L	* INITIAL	FLOC	SPEED	SIZE 20 MIN	SETTING RATE	20 MIN SETTLED TURBIDITY	30 MIN TURBIDITY	pH	COLOR	AL MG/L	FE MG/L	ALK MG/L	HARDNESS MG/L	
1																		
2																		
3																		
4																		
5																		
6																		

* Same as raw unless chemical added prior to addition of coagulants.

STIRRING TIME SPEED G+/1000

MINUTES @ RPM sec^{-1}

MINUTES @ RPM sec^{-1}

MINUTES @ RPM

SETTLING TIME MIN

TREATABILITY
Table 13-1 COAGULATION TESTS

SOLUTION PREPARATION

Alum and Ferric Chloride

Both alum and ferric chloride are usually prepared as a 1% solution by weight (that is 1 g in 100 mls or 1 lb. in 100 lbs). If one has dry alum or ferric chloride the preparation is straight forward. With concentrated liquid solutions (e.g. alum 48.5% by weight) a dilution step has to be done. Any dilution step has to take into account the specific gravity (s.g.)* of the solution being diluted, e.g. 48.5% alum has a s.g. of 1.35. To make up a one percent solution from liquid alum we carry out the following steps:

1 ml of 48.5% liquid alum weighs 1.35g

1 ml contains $1.35 \times \frac{48.5}{100} = 0.65$ g

# of mls containing 1 g $= \frac{1}{0.65} = 1.54$

Therefore add 1.54 mls (or 1 g) of liquid alum to 100 mls to make up a 1% solution.

Note: * weight of solution divided by unit volume (g/cc)

Sample Problems

1. Prepare a 1% solution of ferric chloride if the concentrated solution of 42.3% by weight and the specific gravity is 1.42.

2. How many mls of storage tank alum are required to make up 100 mls of a 1% solution for jar tests if the alum is 48% by weight (s.g. 1.34) when delivered, but diluted 2:1 at the storage tank.

Activated Silica Solution

1. Stock Solution of Sodium Silicate

Weight 348.4 grams of sodium silicate solution "N" Brand, sodium silicate solution as made by Philadelphia Quartz Co., Philadelphia, Pa., U.S.A., and National Silicates Limited, Toronto, Ontario). Dissolve this sodium silicate solution in 500 ml. of distilled water and then dilute to one litre with distilled water. If capped in bottles, this solution will remain stable indefinitely.

2. Stock Ammonium Sulphate Solution

Weight 66.0 grams of ammonium sulphate $((NH_4)_2SO_4)$. Dissolve in 980 ml. distilled water. Kept in capped bottles, this solution is stable indefinitely.

3. Preparation of the Activated Silica Solution

a) Place 20 ml. distilled water in a 100 ml graduated cylinder. Add 10. ml. of stock sodium silicate solution and invert four times to mix.

b) Add 10. ml. stock ammonium sulphate solution and invert 10 times to mix. Let this mixture age for 5 minutes, exactly. Then dilute to 100 ml. with distilled water and invert 10 times to mix. The activated silica solution is now ready for use in the Jar Test. It should be made fresh daily.

c) Each 0.1 ml. of this activated silica solution represents a dosage of 1.0 part per million when added to a one litre water sample in the Jar Test, and, therefore, 1.0 ml. of this activated silica solution represents 10. parts per million of activated silica when added to a one litre sample of water in the Jar Test.

Activated Silica on a Plant Scale (See Page 13-9)

1. To make a 1% Activated Silica Solution:

   a) take 1 gal. of sodium silicate (N - sol. 28.7% SiO_2) and mix with 18 gal. of water.

   b) slowly dissolve 3½ lbs. of sodium bicarbonate in 8 gal. of water

   c) mix a) and b) together and age for 2 hrs., then dilute to 41.6 gal.

2. Alternate Method Using a Mixer

   a) mix 1 gal. of sodium silicate (N - sol. 28.7% SiO_2) with 26 gal. of water

   b) using a mixer, mix at high speed and sprinkle 3½ lbs. of sodium bicarbonate into it until all is dissolved, age for 2 hours, then dilute to 41.6 gal.

Places in Ontario Using Activated Silica

Location	Dosage (mg/l)	Location	Dosage (mg/l)
Blenheim	2	Brantford	7
Cayuga	4	Kingsville	2
Emo	4	Petrolia	
Huntsville	2	Lindsay	
Amherstburg	2.5	Dresden	
Goderich	2	Campbellford	
Haileybury	12	Belle River	
Oakville	2	Thornbury	
Port Hope	2		

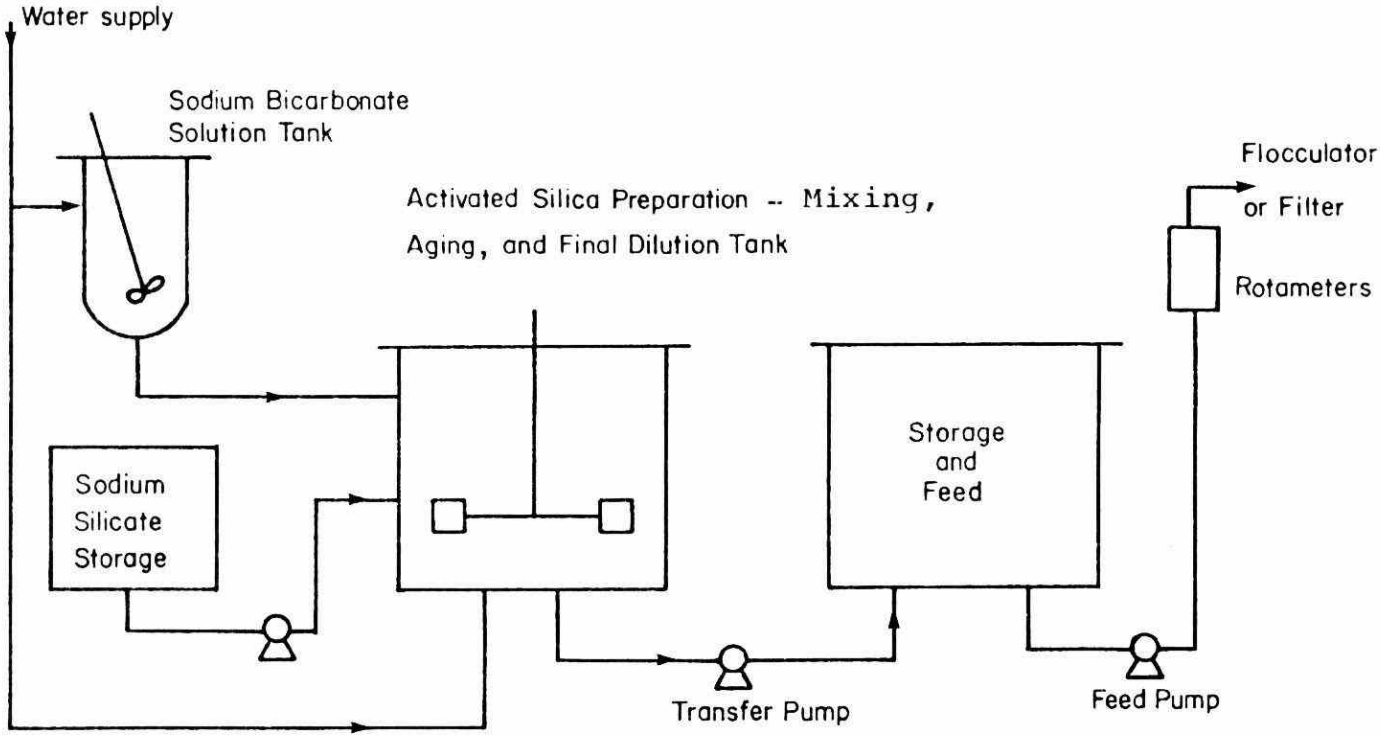


Figure 13-2 Activated Silica Equipment Arrangement

Polymer

Care must be taken when making up polymer solution for jar tests from powdered polymers. Fish eyes or globs of polymer result if the polymer is added to the solution too quickly or if solutions greater than 1% are attempted to be made. It is recommended that 0.05% or 0.1% be made up for jar tests. As the water is being added to the bottle the polymer should be added very slowly to "wet" it as it enters the container. For plant use, a polymer eductor is used. Page 13-14 lists Polymers in use in Ontario and suppliers.

Note

- 1 ml of 1% polymer added to 1000 mls water = 10 mg/l
- 1 ml of 0.1% polymer added to 1000 mls water = 1 mg/l
- 1 ml of 0.05% polymer added to 1000 mls water = 0.5 mg/l

Jar Tests Using Coagulants Only

Jar Tests using coagulants only require a 6-place laboratory stirrer or jar tester, as well as six 1500 ml beakers. The procedure for carrying out the test is:

1. Under each stirring paddle, place a 1500 ml beaker
2. Place into each beaker, from a graduated cylinder, exactly 1000 ml of a fresh sample of the raw water.
3. Note on the test sheet the amount of coagulant that you are going to add to each beaker. This amount will vary from beaker to beaker.
4. Start the stirrer and set it at maximum speed (usually 100 + rpm).
5. Add the coagulant in increasing amounts to each successive beaker. For example, 10 mg/l to beaker #1, 20 mg/l to beaker #2, etc.

NOTE: 1 ml of 1% solution in 1000 ml of water is 10 mg/l

6. After the coagulant dosage has been added to the last beaker, continue running the stirrer at maximum speed (100 + rpm) for another minute.
7. Reduce the speed to 30 rpm and allow the stirring to continue for 30 minutes.
8. Note how long it takes before a floc begins to form
9. Note how well it withstands some stirring without breaking up.
10. Stop the stirrer after 30 minutes. Note how long it takes for the floc to settle to the bottom of the beaker.
11. After allowing the floc to settle for 20 minutes, note the colour and the turbidity of the supernatant (the liquid above the floc). This sample is obtained by using a baster.
12. Remember to note your chemical dosages, mixing time and speed, pH, floc growth characteristics and supernatant analysis on your operating sheets.

13. After allowing the floc 30 minutes to settle to the bottom, filter the supernatant, using the baster as a sampler, through S & S Black Ribbon #589 filter paper (other coarse filter papers are acceptable).
14. Since many filter papers will give off particular matter early in the filtration, the first 75 - 100 mls of sample should be disregarded.
15. Filter another 100 - 150 mls of sample.
16. Perform turbidity, pH, colour and residual aluminum tests on the filtrate.
17. If you have an iron coagulant or a high iron level in your raw water, carry out an iron test on the filtered water.
18. The hardness test is essential in both a softening and a partial softening plant.
19. The alkalinity test is important in soft waters. It can also be used to check your alum dosage. Remember 1.0 mg/l alum reduces the alkalinity by 0.45 mg/l.
20. The jar that gives the best results using the least amount of coagulant should indicate the proper coagulant dosage for your plant.

Jar Tests Using Coagulants Plus Coagulation Aids

1. To determine if either activated silica or polyelectrolyte can help the coagulation-flocculation-sedimentation process, do the following: Repeat the jar test using the best coagulation dosage as determined from step 20 above (or slightly below this dosage), and add varying amounts of coagulant aid as described at step 5 above for the addition of the coagulant. The amount of activated silica added is usually 10 to 20% of the alum dosage used. Polyelectrolyte dosages rarely exceed 1 mg/l.
2. When determining the use of coagulation aids, keep one jar with alum only. Then compare the results when using only alum to the results obtained when a coagulation aid is added to the alum.

3. When applying jar test results to the plant, it is sometimes found that the plant operates better at a chemical dosage slightly different than that indicated by the jar tests. The jar testing is very efficient both in stirring and settling. If the plant is not as efficient as the jar tests, a higher dosage of coagulant may be needed.

4. The regional or district staff of the Ministry of the Environment should be contacted when difficulties arise either in trying to run the jar tests, or in trying to apply the jar test results to the plant.

Polymers and Suppliers

Manufacturer	Address	Products
Alchem Limited (Nalco Chemicals Ltd.)	211 Lakeshore E Oakville, (416) 849-7121 or Zenith 81930	Nalcolyte Series
Allied Colloids Inc.	151 Carlingview Dr. Toronto (416) 678-6020	Percol Series
Calgon Corp.	27 Finlay Brampton (416) 457-5310	Coagulant Aid Series Cat Floc Series
Cyanamid of Canada Ltd.	2031 Kennedy Rd. Toronto (416) 293-8181	Superfloc Series Magnifloc Series
Dearborn Chemicals	3451 Erindale Stn. Rd. Mississauga (416) 279-2222	Aquafloc Series
Dow Chemical	250 Bloor E. Toronto (416) 920-5520	Separan Series purifloc Series
Drew Chemical Co.	Drewcourt Ajax (416) 925-3069	Drewfloc Series

Polymers in Use in Ontario

Location	Product	Approx. Dosage	Use
Arnprior	Nalcolyte 8170	0.02 mg/l	Filter Aid
Lakefield	Nalcolyte 8174	0.5 mg/l	Flocculant Aid
Lake Huron WSS	Separan NP-10	0.05 mg/l	Filter Aid
Moosonee	Separan NP-10	0.5 mg/l	Flocculant Aid
Ohsweken	Cat Floc	1.0 mg/l	Flocculant Aid
Petawawa	Separan NP-10	-	
Rockland	Nalcolyte 8170	0.3 mg/l	Flocculant Aid
Sarnia	Purifloc N-20	0.01 mg/l	Filter Aid
Sudbury	Purifloc A-22	0.5 mg/l	Flocculant Aid
Timmins	Nalcolyte 8170	0.8 mg/l	Flocculant Aid
Windsor	Percol LT 24	0.1 mg/l	Primary Coagulant

Important

Before using any polymer in the treatment process always consult the supplier regarding the toxicity and maximum dosages of the polymer.

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 14

Taste and Odour Testing

OBJECTIVES:

The trainee will be able to:

1. Recall the purpose of and general procedure for the Threshold Odour Test.

2. Define the Threshold Odour Number.

TASTE AND ODOUR TESTING

GENERAL

Taste and odour problems are usually caused by both organic and inorganic materials that have inadvertently entered the raw water source. When this happens, our first objective should be to identify the material that is giving rise to the problem and then close off or slow down its further entry into the water system. The next step is to try to eradicate any material that is residual in the system, by carbon filtration if the contaminant is organic, or by flocculation, and filtration if it is inorganic.

Substances which cause taste and odour problems in water supplies are usually present in very minute quantities. They are of such varied nature that simple laboratory methods cannot be readily used for their analyses. The most suitable method of detecting and measuring the intensities of tastes and odours in the water is probably by the use of one's own senses of taste and smell. These two senses are closely related and it is more convenient to use the sense of smell.This isthe principle of the Threshold Odour Test. This is the most practical method available for the waterworks operator for determining the taste and odour quality in the water.

THRESHOLD ODOUR TEST

Purpose

The purpose of the test is:

1. To check on the odour quality of raw and treated waters.
2. To control odours in the plant.
3. To determine dosages of chemicals required for treatment.
4. To evaluate effectiveness of different treatment methods.
5. To determine or trace the source of contamination.

By means of the odour tests the operator will be able to detect odours far below the levels normally detected by the average consumer.

If the odour tests are conducted on routine basis, the operator can keep close checks on the odour quality in the water. He can keep abreast of any odour developments and take the necessary steps to control the taste and odour problem before the water reaches the consumer.

Odour tests are useful in determining the dosages of chemicals required for treatment. They will help to evaluate the effectiveness of various treatment methods for taste and odour control.

General Procedure

The Threshold Odour Test is performed using a panel, the members smelling samples of an odour-bearing water diluted in various proportions with odour-free water. The diluted samples are placed in a series of flasks and heated to 60^{o}C, and starting with the highest dilution they should be passed around among the panel members. The odours given off by these flasks are compared with that from the flask containing odour-free water. The greatest dilution at which at least three members of the panel concur about the presence of an odour, should be taken as the Threshold Odour Number. (T.O.N.) It is defined as the number of times or the dilution ratio to which a sample of an odour-bearing water must be diluted with odour-free water to reduce its odour level so that it is just detectable.

Precautions

1. Samples for odour tests should be collected in glass containers.

2. Samples should be kept refrigerated.

3. Odour tests should be conducted as soon as possible after the samples have been collected.

4. Chlorinated samples should be dechlorinated.

5. Glassware for odour tests should be kept separate. It should be washed thoroughly with odour-free detergent and water before each test.

6. Odour tests should be conducted in a quiet room where there are no odours present.

7. Care should be taken to prepare the dilutions.

Selection of a Panel

Odour sensitivity varies widely with different persons. Even the same person will not be consistent in the concentrations of odour levels that he can detect from day to day. Wherever possible, a panel of not less than four persons should be selected and assembled to conduct these tests. The persons should be free from any colds. They should not eat or smoke just before they are going to do the tests.

Apparatus Required for the Test

6 or 8 Erlenmeyer flasks 500 ml with ground glass stoppers (32)

2 thermometer, 0^{o}-110^{o}C

1 250 ml graduated cylinder

1 100 ml graduated cylinder

1 50 ml graduated cylinder

1 25 ml graduated cylinder

1 10 ml graduated cylinder

1 large electrical hot plate

1 water bath

1 odour-free water generator (See Appendix A)

Procedure

Determine the approximate range of threshold odour number.

1. Add 200 ml, 50 ml, 12 ml and 2.8 ml of the sample water to each separate glass-stoppered Erlenmeyer flask. Each flask should be numbered.
2. Add odour-free water to make a total volume of 200 ml in each flask.
3. Add 200 ml of odour-free water to another glass stoppered flask which will be used as the reference for comparison.
4. Heat all of the flasks to 60^{o}C in the water bath on the hot plate. (Considerable time can be saved by preheating the odour-free water to 60^{o}C).
5. Shake the flask containing the odour-free water. Remove the stopper and sniff the vapours.
6. Do the same with the flask containing the least amount of odour-bearing water (undiluted sample) and note whether it has an odour, and if so describe what type.

7. If the odour can be detected in this flask, then more dilute samples must be prepared.

8. If the odour cannot be detected in the first diluted sample, repeat this procedure - first sniffing the flask with the odour-free water - with the flask containing the next higher concentration of the odour-bearing water.

9. Continue this process until the odour is clearly detected.

Determine the actual T.O.N. of the odour-bearing water.

1. Based on the results obtained in the preliminary test, prepare a set of dilutions using the following table as a guide.

DILUTIONS FOR VARIOUS ODOUR RANGES			
Sample Volume in Which the Odour First Noted			
200 ml	50 ml	12 ml	2.8 ml
Volume of Sample to be Diluted to 200 ml			
200 ml	50 ml	12 ml	
140	35	8.3	2.8 ml
100	25	5.7	2.0
70	17	4.0	1.4
50	12	2.8	1.0

2. Dilute each sample of odour-bearing water to 200 ml with odour-free water.

3. Add 200 ml of odour-free water to two or more flasks to be inserted into the series as a reference and a blank for comparison.

4. Mark each flask with a number or a letter.

5. Heat all the flasks to 60^{o}C and then arrange them so their odour is unknown.

6. Shake the flask containing the odour-free water. Remove the stopper and "sniff" the vapours.

7. Take up the other flasks one by one, remove the stopper and "sniff" the vapour comparing each one with the one containing the odour-free water.

8. Record the results for each flask as "positive" (+) if an odour was observed and negative if no odour was observed.

Example

code	1	2	3	4	5	6	7
ml sample	12	0	17	25	0	35	50
response	-	-	-	+	-	+	+

9. The dilution containing the smallest volume of odour-bearing water which gives a positive reaction is the threshold odour number (T.O.N.). In the above example, the first detectable odour occurred when 25 ml of odour-bearing was diluted to 200 ml with odour-free water.

Therefore $T.O.N. = \frac{200}{25} = 8$

The following table gives the dilutions and their corresponding T.O.N. values.

THRESHOLD ODOUR NUMBERS CORRESPONDING TO VARIOUS DILUTIONS

Sample Volume Diluted to 200 ml	T.O.N.	Sample Volume Diluted to 200 ml	T.O.N.
200	1	12	17
140	1.4	10	20
100	2	8.3	24
70	3	5.7	35
50	4	4	50
40	5	2.8	70
35	6	2	100
25	8	1.4	140
20	10	1.0	200

T.O.N. = Threshold Odour Number

REFERENCES

(1) STANDARD METHODS for the Examination of Water and Wastewater, 13th Edition. APHA AWWA WPCF 1971 pp. 248-254

(2) Taste & Odour Control in Water Purification West Virginia Pulp & Paper Co. (Chemical Division) 230 Park Avenue, New York, N.Y. 10017 (1966). This publication is available on request from:

Standard Chemical Limited
60 Titan Road
Toronto, Ontario M8Z 1J8

Preparation of Odour-Free Water

To conduct threshold odour and taste tests, an adequate supply of odour-free water should be available. Odour-free water is required for preparing the dilutions of the odour-bearing samples, for rinsing all glassware free of odours and for use as a blank in the test.

Odour-free water should be prepared as needed because it will absorb any odours that may be in the room. Most tap waters are suitable as sources for the preparation of odour-free water. This is done by passing tap water through the odour-free generator, as shown in the diagram, at the rate of 0.1 liter per minute. This is approximately 20 minutes of contact time with the carbon.

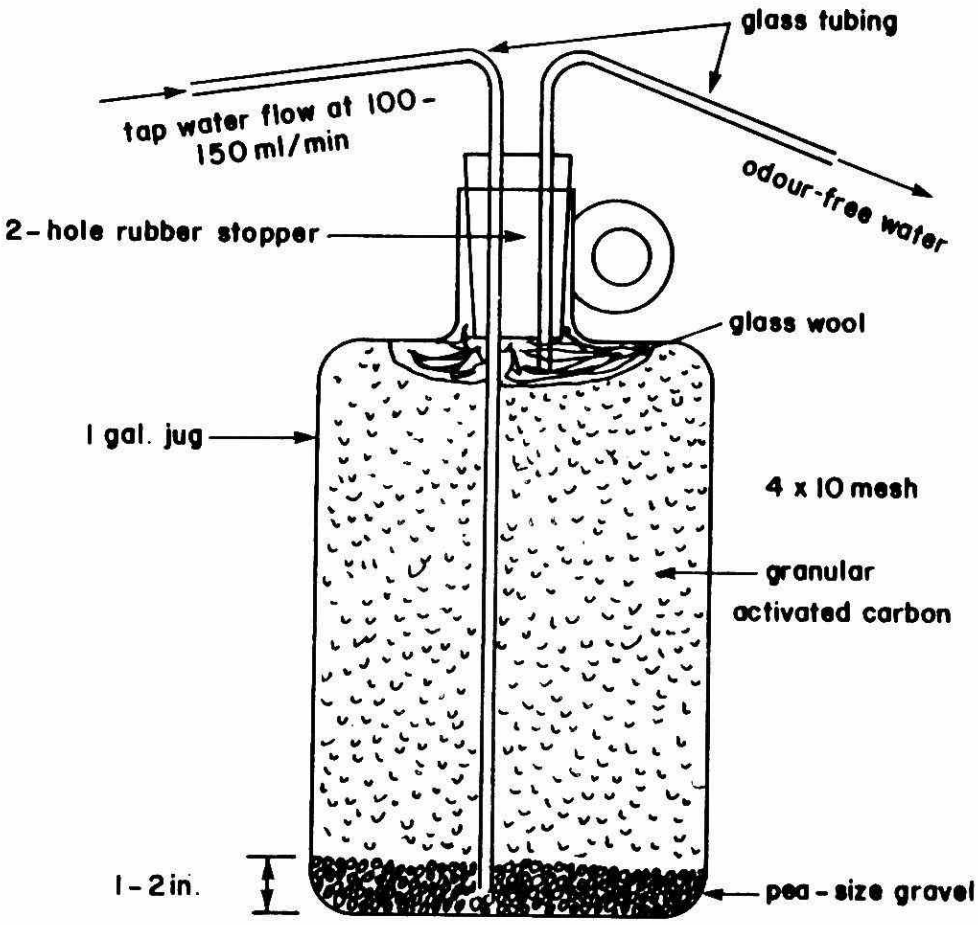


FIGURE 14-1 **ODOUR-FREE WATER GENERATOR**

GLOSSARY OF TERMS

The following definitions are intended only as aids in the study of this manual.

absorption -
The taking up of one substance into the body of another.

ABS -
Abbreviation for Sodium alkyl benzene sulfonate.

adsorption -
(1) The adherence of a gas, liquid or dissolved material on the surface of a solid.

(2) A change in concentration of gas or solute at the interface of a two-phase system.

aeration -
(1) The bringing about of intimate contact between air and a liquid by one or more of the following methods:

a. spraying the liquid in the air,
b. bubbling air through the liquid,
c. agitating the liquid to promote surface absorption of air.

(2) The supplying of air to confined spaces under nappes, downstream from gates in conduits, etc. to relieve low pressures and to replenish air entrained and removed from such confined spaces by flowing water.

(3) Relief of the effects of cavitation by admitting air to the section affected.

air gap -
The distance between the lowest opening of a pipe supplying water to a tank or plumbing fixture and the flood-level rim of the receptacle.

algae -
Tiny plants, usually living in water and often green in colour.

algicide -
Anything applied to kill or control algae.

anionic -
Relating to negatively charged ions.

aquifer -
Porous, water-bearing formation of rock, sand, or gravel.

artesian aquifer -
An aquifer where the water is under pressure and will rise to a higher elevation if afforded an opportunity to do so.

backflow -
The backing up of water through a conduit or channel in the direction that is opposite to normal flow.

bacteria -
Single-celled microscopic plants living in soil, water, organic matter or the bodies of plants or animals.

backwash -
The method used to clean filter media by reversing the water flow.

booster station -
A pumping station in a water distribution system, used to increase the pressure in the mains on the discharge side of the pumps.

chlorine demand -
The difference between the amount of chlorine added to a water or wastewater and the amount of chlorine residual left after a certain length of time.

chlorine residual -
The amount of chlorine still left available after a certain length of contact time.

clear well -
Reservoir for storing filtered water.

coagulants -
In water and wastewater, chemicals used to thicken finely divided suspended solids into groups for easy removal.

coagulation -
In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.

coliform -
A group of bacteria normally living in the intestines of man and animals and are also found elsehwere in nature. They are pollution indicators in water supplies.

colloidal -
Too finely divided to settle; requiring coagulation, biochemical action, or membrane filtration for removal.

combined chlorine residual -
The concentration of chlorine combined with ammonia as chloramine or as other chloro-derivitives, yet is still available to oxidize organic matter or carry on disinfection of water.

cone of depression -
A cone-shaped hollow made in a water table as water is drawn from a well.

contact basin -
A basin used to put water or wastewater in contact with chemicals or other materials; for example, a chlorine contact chamber.

contamination -
The presence of microorganisms, chemicals, or wastes that make water unfit for use.

diatomaceous earth -
A fine soil made up mostly of the skeletal remains of diatoms.

diatoms -
Single-celled microscopic algae that grow in or on water and have skeletons of silica.

disinfection -
Destruction of disease causing microorganisms by physical or chemical means (chlorination or boiling of water).

distribution system -
A system of piping, canals, and associated equipment used to distribute a water supply to consumers.

drawdown -
The lowering of a water level in a well or a tank.

effluent -
In wastewater treatment, wastewater or other liquid, partially or completely treated or in its natural state, flowing out of a reservoir, basin, treatment plant, or industrial treatment plant, or part thereof

enzyme -
A protein that promotes a chemical reaction, enabling it to continue at body temperature.

filter cake -
Dewatered sludge or sediment.

filter media -
The material through which water or wastewater is filtered.

filtration -
The process of passing a liquid through a filter to remove suspended solids.

floc -
Small jelly-like masses formed in a liquid by adding a coagulant.

flocculation -
The collection of coagulated suspended solids into a mass by gentle stirring.

flocculation aids -
Materials added to liquid to form flocs.

flocculator -
Mechanical equipment used to encourage the formation of floc in liquid.

hydrologic cycle -
The movement of water from the atmosphere to the earth and back to the atmosphere through precipitation, infiltration, storage, transpiration, evaporation etc.

hydrolysis -
A chemical process of decomposition using the addition of water. Also, the process solid matter goes through to become liquid.

indicator bacteria -
Coliforms that point to the presence of intestinal pathogens.

influent -
Water or wastewater flowing into a treatment plant or any of its units.

injection wells -
Wells created to recharge groundwater.

inorganic -
Made of matter that is not plant or animal.

ion exchange
A chemical process in which ions from two different molecules are exchanged.

ionizing -
Creating ions by adding electrons to, or removing them from, atoms or molecules.

iron bacteria -
Bacteria that use iron as food and discharge its compounds in their life processes.

leaching -
Percolating liquid through soil or other solids to remove the soluble ingredients.

metabolism -
The process in which food is used and wastes are formed by living matter.

MF -
Membrane filter (used in bacteriological lab test)

microbes -
Microscopic organisms, especially pathogenic bacterium.

micro-organisms -
Minute organisms, either plant or animal, invisible or barely visible to the naked eye.

MPN -
Most PROBABLE Number (used in bacteriological lab test).

nutrient -
Food for the growth of organisms.

organic -
Made of matter that is plant or animal.

ozonization -
The act or process of charging or treating with ozone. Also, the conversion of oxygen into ozone. Used for disinfection purposes.

pathogenic -
Disease-producing bacteria.

permeable -
Having pores or openings that permit liquids or gases to pass through.

pH -
The measure of the acid/alkaline balance, expressed on a scale of 0 to 14, with 7 being neutral; 7 to 0 increasing acidity, and 7 to 14 increasing alkalinity.

pressure head -
A measure of the pressure exerted by a fluid.

pseudomonad -
Short rod-shaped bacteria, some of which live on dead or decaying organic matter, or cause disease.

pumping level -
The height where water stands in a well during pumping.

reducing agent -
A substance that causes the loss of an electron.

retention time -
Detention time; the length of time that water or wastewater is held in a unit for any treatment.

septic -
Anaerobic (decomposition without oxygen).

spores -
Walled, single to many-celled reproductive bodies of microorganisms, able to produce new organisms directly or indirectly.

staining -
Colouring specimens for microscopic study. Also, colouring or discolouring anything.

static level -
The height of a water surface when groundwater is not being removed.

supernatant -
The liquid standing above a sediment. In sludge digestion, the liquid standing between the sludge at the bottom and the scum at the top.

surface water -
All water found on the surface of the earth.

suspended solids -
(1) Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removable by laboratory filtering.

(2) The quantity of material removed from water or wastewater in a laboratory test, as prescribed in "Standard Methods for the Examination of Water and Wastewater" and referred to as non-filterable residue.

titration -
The method finding how much of something is in a solution by measuring how much of something else is needed to cause a chemical change.

total solids -
The sum of dissolved and undissolved constituents in water or wastewater, usually stated in milligrams per litre.

transpiration -
The process by which plants return water to the atmosphere.

turbidity -
A condition in water caused by suspended matter; murkiness.

volatile solids -
The quantity of solids in water, wastewater, or other liquids, lost on ignition of the dry solids at 550°C.

water hammer -
Loud blows caused by moving water against the sides of its containing pipe.

watershed -
An area that drains into a particular body of water or water course.

weir -
A dam or enclosure in water or wastewater used to raise the water level or change the direction of its flow; with notches or a crest, it measures the flow.

well head -
The top of the well.

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